NAVAL PROFESSIONAL PAPERS

No. 15

SHIPS, GUNS, AND ARMOR

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PAPERS AND DISCUSSIONS

ON

SHIPS, GUNS, AND ARMOR.

REPRINTED FROM VARIOUS SOURCES.

BUREAU OF NAVIGATION,
NAVY DEPARTMENT.

WASHINGTON:
GOVERNMENT PRINTING OFFICE.
2252 S G
1883.

NOTE.

The Naval Professional Papers are a continuation of the series of Navy Scientific Papers previously published by the Bureau of Navigation.

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INAUGURAL ADDRESS OF THE PRESIDENT OF THE BRITISH INSTITUTION OF CIVIL ENGINEERS.

At the ordinary meeting of Tuesday, the 10th of January, Sir W. G. Armstrong, C. B., F. R. S., delivered an inaugural address as president.

He observed that it had been the practice of his predecessors in the chair to select topics for their address that had reference to branches of engineering which operated to increase the productiveness of human industry, and there were many who would contend that all engineering efforts ought to center upon that object. It might be fully admitted that the general amelioration of the material condition of the world was the noblest object of engineering science; and if men and nations ceased to be bellicose and rapacious, such would naturally be the direction which all engineering practice would take; but this was a world of contention, where no individual state could insure its independence and carry on its industrial occupations in safety without protecting itself against the possible aggression of its neighbors.

Thus it was that the science of the engineer was invoked for the purposes of war as well as for those of peace; and it was probable that the engineering element would in future enter more and more largely into the operations of war, until the issue would be chiefly dependent upon the superiority of mechanical resources displayed by one or other of the contending parties. There was no country in the world less disposed to be aggressive than our own, but there was none so likely to incite the greed of an assailant, or so vulnerable in relation to its commerce. War indemnities had degenerated into mere exactions proportioned to the wealth of the vanquished; and England, being the richest of nations, offered the highest premium for successful attack. As to commerce, England had more than one-half of the ocean carrying trade of the whole world in her hands, and her ships, swarming over every sea and conveying merchandise of enormous value, would in the event of war invite the depredations of hostile cruisers. We had seen in recent years what ravages a single armed ship could inflict upon a mercantile navy incomparably smaller than our own, and in our case it was not only property, but indispensable food that was at stake. The ever-increasing population of Great Britain had already far outgrown its internal means of support, while the increasing cheapness of imported food so discouraged native agriculture that we might expect our future dependence upon foreign supply to increase even more rapidly than our population. This was not the occasion to discuss either moral questions affecting war or political questions concerning free trade. We had the stern fact before us that national defense was in our case peculiarly a necessity, and the question how it could best be effected from an engineer's point of view was a legitimate subject for this address.

England must always be chiefly dependent for security upon our naval power, but we could not hope that she would ever again be so dominant at sea as before the introduction of steam navigation. So long as naval superiority depended upon seamanship and an unlimited supply of sailors, no nation or combination of nations could compete with us; but as soon as it became established that fighting ships could be maneuvered with more certainty and precision by the power of steam than by the power of wind, a revolution began which had gradually made naval warfare a matter of engineering rather than of seamanship. The introduction of rifled ordnance and percussion shells was the second step in this revolution, and had the effect of condemning as useless the whole fleet of wooden ships with which all our victories had been won, and which were the pride of the nation. Then commenced that contest between guns and armor which had gone on to this day, and had not yet been decided. Nor would it, in all probability, ever be decided, seeing what an *ignis-fatuus* finality was. The most recent stage of this revolution was that marked by the introduction of torpedoes, against which our ponderous iron-clads were no more secure than ships of thinnest iron.

These constantly changing phases of attack and defense had placed our naval authorities under extreme difficulty in deciding upon questions of ships and armament. To stand still was impossible, while to act upon uncertain data was sure to lead to mistake.

The necessary consequence had been that types and patterns of ships had been continually changing, and vessels costing vast sums of money had become nearly obsolete almost as soon as made. We could not wonder that so long as invulnerability was conceived to be attainable, great sacrifice should be made for its accomplishment; but with our present knowledge, which it would be unfair to apply to a criticism of the past, we might feel assured that invulnerability was a chimera. Not only did we see that armor was unavailing against torpedo attack and ramming, but we were justified in concluding that every attempt to increase resistance to projectiles would be quickly followed by a corresponding increase in the power of artillery. Our early iron-clads, like the *Warrior*, were plated all over with armor 4½ inches thick—a thickness which could now be pierced with field pieces. To resist the most powerful guns now afloat armor of at least 2 feet in thickness was required; and in order to reconcile the constantly increasing thickness with the weight which the ship was capable of carrying, it had been necessary to restrict the area of armored surface to ever narrowing limits, leaving a large portion of the ship without protection. In those magnificent and tremendous vessels which the Italians were now building, the armor would be withdrawn from every part except the battery, where guns of 100 tons would be placed, and where the armor would be confined to a narrow belt of great thickness. Everything of importance that projectiles could destroy would be kept below water level, and, so far as artillery fire was concerned, the ships would be secured against sinking by means of an under-water deck and ample division into compartments. Armor, therefore, seemed gradually contracting to the vanishing points; but until it actually disappeared it was probable that no better application of it could be made than had been decided upon by the acute and enterprising naval authorities of Italy for the great ships they were now constructing.

The dread of the terrible effects of the fragments of shells bursting amidst a crowded crew, and the apprehension that the smoke from the explosion, when it occurred between decks, would paralyze the service of the guns, had conduced more than anything else to the adoption of armor. Methods of avoiding or lessening these dangers otherwise than by the use of armor had been little considered, yet the alarming aspect of the case was greatly altered when we reflected that by the application of mechanical power to do what had hitherto been done by a multitude of hands, the exposure of a crowded crew could be avoided, and also that the guns might all be mounted on an open deck, where the smoke from shells would speedily clear away.

As to the comparative liability of an iron-clad and an unarmored ship to be sunk by projectiles, there was much less difference between them than was generally supposed; because the unarmored ship, though freely penetrable, might be so constructed that the entrance of water by perforation would not extensively flood the ship, unless it took place at a great number of critical places. Indeed, by introducing an under-water deck with divisional spaces, and by the partial application of cork, as in the *Inflexible*, for displacing influent water and thereby preserving stability, and also by a proper distribution of coal for the same purpose, an unarmored ship might be rendered almost incapable of being sunk; and it was rather surprising that so little attention had been directed to the attainment of that object. It was not too much to say that for the cost of one iron-clad we could have three unarmored ships of far higher speed and carrying collectively three armaments, each equal to that of the armored vessel.

It might be asked, which would be the better investment? If it were imagined that the three were matched in combat against the one, it would be perceived that, in addition to their numerical superiority, the former would possess many advantages. Being smaller, they would be more difficult to hit. Being swifter, they could choose their positions, and be free to attack or retreat at pleasure. Being more nimble in turning, they would be better adapted both for ramming and for evading the ram of their adversary. Finally, the conditions of superior speed and agility would favor their use of torpedoes and submarine projectiles, although it was a question whether, for the sake of a much needed simplification, it would not be better to confine that species of attack to separate vessels specially constructed for that one particular purpose. Even if the utmost advantage she could possess were conceded to the iron-clad, viz, that of being impenetrable by the guns of her opponents, she could not prevail in a contest of three against one, unless, by the use of securely protected artillery, she could keep her assailants at bay, and gradually destroy them by her fire if they persisted in their attack. Such might be the issue if the allied vessels had nothing but guns to oppose to guns, but they would naturally, under such circumstances, place their men below out of the reach of projectiles, and then attack with their rams or torpedoes. With the crews in safety, it was scarcely possible that unarmored vessels, with underwater decks and all their machinery beneath, should suffer any disabling injury by being pierced in a few places by either shot or shell.

But take the much more probable alternative of the armored vessel being penetrable by the guns which would be used against her. In that case her enemies might elect to make the contest one of artillery. On their part, armor-piercing projectiles would be used, which, on penetrating the thick sides of the iron-clad, would carry inboard a mass of broken material far larger in quantity than the fragments of the shells with which they would be assailed, and quite as destructive in effect. The iron-clad would have to sustain the converging fire of the three ships, each carrying the same armament as her own, and her swift and nimble adversaries would steam round and round her, directing their fire on the most vulnerable points, and ever ready to seize a favorable moment to dash in and finish the contest by ramming. In either case, therefore, the iron-clad would be overmatched by a combination of unarmored vessels representing the same pecuniary value. Without entering into technical questions concerning fleet-fighting, it seems reasonable to believe that the result would be the same if the number engaged on each side were proportionately multiplied. Inferiority of speed and of number would still give the choice of position, and secure the advantage of converging fire, besides which the greater power of division and of concentration must always belong to the more numerous fleet.

But if iron-clads were not needed for the purpose of opposing iron-clads, it was difficult to see for what purpose they were wanted at all. For every other kind of service a numerous fleet of smaller and swifter vessels, unencumbered with armor, would clearly be preferable. To protect our commerce, to guard our extensive seaboard against invading flotillas, to lend naval assistance to our colonies in case of need, and generally to maintain our supremacy at sea, we required a far more numerous navy than we possessed or could afford to possess unless we vastly reduced our expenditure on individual ships, and to do this we must dispense with armor.

It might, perhaps, be rash entirely to abandon armor so long as other nations continued to use it, because nothing but the experience of an actual war would remove all question as to its possible utility; but considering the indisputable value of a numerous fleet of swift and powerfully-armed ships, built with a view of obtaining the maximum amount of unarmored defense, and considering that such vessels, unlike armorclads, could never grow much out of date, it did seem to be expedient that the chief expenditure of this country should be upon ships of that description. Lightness should be the special aim in the construction of such vessels. Steel plates should be used for the hulls, and guns and engines should be of the least possible weight consistent with the necessary power. Every ton of weight saved would enable higher speed to be attained, and there was probably no quality in a fighting ship which would so much develop in importance as that of swiftness.

Messrs. Thornycroft have led the way in showing what extraordinary speed could be realized in diminutive vessels, by reducing to the utmost the weight of every part of the structure and its contents; and although we could not expect to attain proportionate speed by the same method in ocean-going ships of war, yet there could be no question that we might have far swifter ships than at present if lightness were made the principal object, instead of the prevalent practice of loading ships with cumbrous armor, in the vain hope of rendering them invulnerable. Light unarmored ships, designed by Mr. George Rendel, had lately been built in this country for foreign powers which with a displacement of only 1,300 tons had attained a speed of 16 knots an hour. They carried coal for steaming 4,000 miles and had already actually steamed 3,500 miles without replenishing. They were each armed with two 10-inch new-type guns, which had nearly an all-round fire, and were capable of piercing 18 inches of iron armor; and with four 40-pounders on the broadsides. It was a very serious question what could be done in the event of a number of such vessels as these being let loose upon our commerce. At present there was not a single ship in the British Navy carrying an armament competent to engage them, that could overtake them in pursuit or evade their attack when prudence dictated a retreat.

Confidence was often expressed in our mercantile marine being capable of furnishing on an emergency a supply of vessels fit to be converted into cruisers; but where were there to be found amongst trading or passenger steamers vessels possessing a speed of 16 knots, with engines and boilers below water level and having an under-water deck to save them from sinking when penetrated by projectiles at or below the water line? From his own experience he knew how difficult it was to adapt mercantile vessels to the purpose of war, and how unsatisfactory they were when the best had been made of them. It was alarming to think how unprepared we were to repress the ravages which even a small number of swift marauding vessels properly constructed and armed for their purpose could inflict upon the enormous property we had at all times afloat, and how little we could hope to clear the sea of such destructive enemies, by cruisers improvised out of ready-made steamers, destitute of all the conditions necessary to render them efficient for such a service. It must ever be borne in mind that it was not merely the loss of property and interruption of trade that we had to fear, but also the interception of food supplies; and that the more our population increased and our agriculture declined, the more terribly effective for reducing us to submission would be the stoppage of those supplies.

The president then adverted to harbor defense. He pointed out that many of our iron-clad forts had already outlived the stage of artillery progress for which they were adapted. He expressed his opinion as to the best method of rendering large guns effective in shore batteries. He dwelt upon the value of gunboats considered as floating gun-carriages, and used in combination with torpedo craft and submarine mines, all of which he suggested might be committed to the management of trained naval-engineer volunteers resident on the spot.

He said it would be a grand development of the volunteer movement of which this country was so justly proud if it were thus to be extended to harbor defense, and he was informed that so far as the use of submerged torpedoes was concerned a project of intrusting their employment to a corps of volunteer engineers was already under consideration.

The superior education and intelligence of the class from which our volunteers were mostly supplied would especially fit them for the discharge of duties involving skill and discretion, such as would be required in the handling of electrical apparatus, and we might be sure that wherever dash was needed in the use of torpedo boats there would be no lack of that quality amongst volunteers in the hour of trial. On the subject of artillery, he described the progress of gun manufacture since the introduction of rifled ordnance, prior to which a gun was simply a tube of cast iron or bronze closed at one end.

He also discussed the question, what, under the present conditions and prospects of steel manufacture, should be our practice as to the use of that material for artillery purposes. He was then led to speak of a system of construction which had not passed through the experimental stage, but which, from the results it had already given, promised to attain a wide application. He referred to that system in which the coils surrounding the central tube consisted of steel wire, or ribbons of steel, wound spirally upon the tube. To those who objected to welded coil tubes on the ground of supposed deficiency of longitudinal strength this mode of construction must appear especially faulty, inasmuch as lateral adhesion, instead of being, as contended, merely deficient, was altogether absent, while to those who advocated the present coil system this variety must commend itself as affording the greatest possible amount of circumferential strength that could be realized from the material employed. Steel in the form of wire, or drawn ribbon, possessed far greater tenacity, and also greater toughness, than in any other condition, and in applying it to guns there was perfect command of the tension with which each layer was laid on.

He then alluded to the labor of those who had worked in this direction, and referred to a 6-inch breech-loading gun of this construction made at Elswick and tried in the beginning of 1880. He stated that the charges used with it were large beyond precedent, and the energies developed proportionately high. Being satisfied with the results obtained with this gun, a second one of larger dimensions had been commenced, and was now finished. Its caliber was 26 centimeters, or about 10¼ inches. Its length was 29 calibers, and its weight was 21 tons. In the previous gun he depended for end strength upon the thickness of barrel only, but in the new one layers of longitudinal ribbons were interposed between the coils in the proportion of one longitudinal layer to four circular layers. The longitudinals were secured to the trunnion ring at one end and to a breech ring at the other, and were in themselves calculated as sufficient to resist the end strain on the breech, independently of the strength afforded by the tube. The whole was incased in hoops shrunk upon the exterior of the coil for the treble purpose of protection from injury, of preventing slipping in the event of the failure of an external strand, and of adding to the strength of the gun. This gun had already been tried, and had given results which, in relation to its weight, were unexampled, except by its 6-inch predecessor.

Various attempts had also been made abroad to reduce this system to practice, and it was understood that the French were at present engaged in making experimental guns upon the same general principle. With regard to the ribbon form of section, he preferred it to a square section of equal area, as being more favorable for bending over a cylinder, but any rectangular form was better than round wire, on account of the flat bending surface it afforded.

He then discussed the subject of breech-loading and muzzle-loading, and the various forms of rifling. He also described the many changes that had been found necessary in the form and manufacture of powder for heavy ordnance, and the difficulties which still remained to be overcome.

As to the mounting of guns in forts and ships, he remarked that the difficulties of the problem were much greater than was commonly supposed. It was certain that machinery could be no longer dispensed with for working the guns, and that engine power must be used to economize labor and avoid exposure of the men. In the days of cast-iron smooth bores the heaviest naval gun weighed 95 cwt. and it was deemed impracticable to exceed that limit in a ship. At the present time the heaviest naval gun in the British service was 80 tons, and guns of 100 tons were carried in Italian ships. Instead of projectiles weighing as a maximum 94 pounds and charges of 16 pounds, we had now to handle projectiles of 1,500 pounds and charges of 450 pounds and to keep pace with foreign navies those limits of weight must be greatly exceeded. Even if it were possible to deal with guns and ammunition of such weights by manual labor, the multitude of men required for the purpose would be greater than could find standing room at the guns. Up to a certain point hand power might be so aided by machinery as to enable larger guns to be worked by men than was formerly deemed possible; but the mechanism required to render hand labor available was quite as liable to be disabled by an enemy's fire as that which would be applied in connection with engine power. There was, therefore, no reason in this respect for employing a numerous gun crew in preference to inanimate power. Automatic methods of running out the gun, by which the gun was lifted in recoiling by slides or radius bars and recovered its position by gravitation, might, in many cases, be advantageously used to save labor, but in a ship the varying inclination of the deck interfered with uniformity of action. The upward motion of the gun also involved the objection of a higher port, and it added greatly to the downward shock, which became very severe on the deck where the guns were large and were fired at considerable elevation with such heavy charges as were now usual. Steam power acting through the medium of hydraulic pressure was already largely applied in recent ships for effecting all the operations of working the guns, and where such power was used there was nothing to gain by automatic action for returning the gun into firing position. In considering these various mechanical arrangements now applicable to naval warfare, we perceived the growth of the engineering element in our ships of war, and the importance of mechanical as well as nautical acquirements on the part of the officers, as also, in a less degree, on that of the men. Breech-loading guns, carriages fitted with all modern appliances, shot and powder lifts, mechanical rammers and torpedo apparatus, all combined with steam or hydraulic machinery or with both, constituted mechanisms requiring to be supervised by officers qualified as engineers, and to be handled by men trained in the use of machinery.

Before drawing to a conclusion he would advert to a subject of grave national importance. Our navy was at present armed with guns which could not be expected to contend successfully with the best modern guns that could be used against them. Happily, most of the older ships of foreign powers were in the same predicament; but all their new vessels, and some of their older ones, were being armed with artillery which, weight for weight, was far superior in power to that of our navy. Our service guns had simply been overtaken in that rapid progress of artillery which had been going on for the last eight or ten years; and it might be doubted whether any partial remodeling during that period would have averted the present need of re-armament, while it would certainly have involved great sacrifice and confusion of ammunition and stores. But a new departure could not longer be delayed. An irresistible demand had arisen for breech-loading guns, and it was imperative to combine with the introduction of that system such other modifications of construction as would realize the increase of power which we now knew to be attainable.

It might, however, be asked, what better prospects of finality there was now than we had ten years ago? As to absolute finality, it would probably never be reached, but the country might take some comfort in the reflection that every stage of progress narrowed the field for further development. There was already no substantial room for improvement in the accuracy of guns; and as to power, we were nearly approaching the limit at which severity of recoil and extravagant length of gun would prohibit further advance.

We might go on building larger guns almost without limit, though he doubted the policy of so doing; but mere increase of size did not revolutionize system. There seemed, therefore, to be more hope of permanency now than at any former period; but whether this were so or not, we could not without danger remain passive.

What, then, should our Government do in regard to the great work of rearming the fleet? He took it for granted that all new ships would be armed with the best guns that could now be made, and that the more important of the older vessels would speedily receive the same advantage; but beyond this, so long as experience of novelties was deficient, it was a case for cautious procedure. In the mean time no expense should be spared in judicious experiments, seeing that the expense of experiments was trifling in comparison with that of mistakes. Above all, the Government should pursue such a course as would bring into full play the abundant engineering resources of this highly mechanical country for increasing the efficacy of our national defenses.

ARMORED SHIPS AND MODERN GUNS.

By J. D'A. Samuda, Esq., M. I. N. A., *Vice-President.*

[Read at the twenty-third session of the Institution of Naval Architects, 29th March, 1882; the Right Hon. the Earl of Ravensworth, president, in the chair.]

This subject, which from the introduction of iron-clad ships has engaged the most earnest attention of the naval architect and marine engineer, has acquired additional importance from the fact that Sir William Armstrong has, on being elected to his important position of president of the Institution of Civil Engineers, made it the subject of his inaugural address in January last, and has used the weight of his authority to advocate the chief expenditure of this country on unarmored vessels of great speed and carrying armor-piercing guns, and to prove that armor-clad ships should be treated as obsolete.

While the statement of facts on which he bases his arguments is such as may be freely admitted, his conclusions, to my mind, are radically and wholly wrong; and the effect of such conclusions, by such an authority, and so ably advocated, appear to involve so dangerous a departure from the present policy of the admiralty and the legislature that I believe I am best conducing to prevent such a national calamity as the acceptance of these views would entail, by bringing the subject under the notice of this Institution, and inviting that discussion and expression of opinion that cannot fail to be valuable in strengthening the House of Commons and the executive in forming a correct view of the important issues involved in the changes advocated.

To do full justice to Sir William Armstrong's argument, his talented and eloquent address should be specially referred to, but the principal facts relied on may be shortly stated to be these:

1. To resist the most powerful guns afloat, armor of 2 feet thick is required, and it has been necessary to restrict the area of armor surface to ever-narrowing limits, and that armor, therefore, seems gradually contracting to the vanishing point.

2. That even if the victory of armor over guns be established, it would still be a question if it would be worth while to incur the expense of continuing it to resist projectiles, seeing that vessels must still remain assailable by rams and torpedoes, and liable to be lost by casualties other than those of war.

3. That the function of armor may in a very considerable degree be fulfilled by coal, if judiciously applied for that purpose.

4. That as to the comparative liability of an iron-clad and an unar-

mored ship to be sunk by projectiles, there is much less difference than is generally supposed.

5. That for the cost of one iron-clad we could have three unarmored ships of far higher speed and carrying collectively three armaments, each equal to that of the armored vessel; and he then describes a combat between three unarmored cruisers and one iron-clad, considered to be fairly matched, *because representing the same pecuniary value*, and assumes the victory would lie with the three unarmored ships; and, without entering into the technical questions concerning *fleet fighting*, concludes that the result would be the same if the numbers engaged on each side were proportionately multiplied.

6. He argues that we require a far more numerous navy than we possess, *or can afford to possess*, unless we vastly reduce our expenditure on individual ships, and to do this we must dispense with armor, and that the chief expenditure of the country should be upon fast unarmored ships, with armor-piercing guns.

7. He condemns the use of cruisers improvised out of ready-made merchant steamers, and forcibly points out the importance of the police service of cruisers by reminding us of the enormous property we have at all times at sea in our ships, and that, in addition to their loss, we have also to guard against the interception of food supplies, and that the more our population increases and our agriculture declines, the more terribly effective for reducing us to submission would be the stoppage of those supplies.

I agree entirely in this last suggestion. I have never advocated a reliance on improvised ready-made steamers, and though, under great pressure, they would be better than nothing, I hold that special and suitable cruisers, and to the extent expected to be required, are what we ought to rely on for such services as they are suited to. Neither can the importance of their mission be too strongly insisted on, knowing, as we do, that we never have more than four months' food in the country, and the terrible straits we must be reduced to if, from any cause, a stoppage of our imported supplies were to take place.

Before dealing with the important issues I would, in passing, observe that many of the arguments in Sir William Armstrong's paper employed to establish the greater value of unarmored ships over iron-clads, really apply equally to both classes, and consequently lose all force when used in support of one only.

Again, after admitting the advantages of steel-faced armor, it is argued that a vessel covered with it, if pierced by a shot, will receive as much or more damage than an unarmored ship similarly pierced, whereas, from their extreme tenacity, fragments from steel-faced plates, as a rule, never break off, and the damage to the inside of the iron-clad would be almost restricted to the passage into it of the penetrating shot.

This might not be the case when the penetrating power of the shot was very greatly in excess of the strength of ship and armor plate to resist it; the injury then would probably extend over a larger area than in a weaker ship, as one can imagine that the strong frames and girders behind the armor might be displaced; but even then I doubt if the damage inside the vessel would be equal to that resulting to an unarmored ship from a shell bursting on a thin plate.

No credit is taken for the great advantage the iron-clad would have from her greater size, giving a steadier platform in moderate or rough weather, and insuring much greater accuracy of aim.

Nor is credit taken for protection for engines, boilers, and steering apparatus, which can be obtained by armor, while it is not practicable at the present time to place the machinery in fast and full-powered vessels sufficiently below water to protect it from an enemy's shot, nor would it be possible in such cases to give complete protection by coal.

The fact is lost sight of that an armored vessel can only be attacked by very heavy guns, and would be assailed by very few shot, while an unarmored vessel, being vulnerable by light guns, which are carried in greater numbers, would be assailed by many shot, and with the probability of a greater number of hits; and even light armored vessels would, to a great extent, possess these advantages, as it is seldom in a naval engagement that a shot can be made to strike at right angles, and the power of resistance of the armor plate increases rapidly as this is departed from.

There also appears to exist throughout his argument a conviction that unarmored ships must possess superior speed and the advantages which would result from it; but I know of no reason for this conclusion, and see no engineering necessity for preventing iron-clads being constructed to attain whatever speed their unarmored opponents possessed, and a reference to practical experience will, I believe, also show that hitherto this has been accomplished.

Then, as to basing a comparison of merit of the two systems on the number of ships that the same money would purchase, and suggesting a combat between the *money* value of the two classes so obtained, nothing can be more misleading. If the services of iron-clads are wanted because cruisers cannot properly substitute them, no one is going to restrict the number of them to meet what Sir William Armstrong calls a "good investment," or "to represent the relative cost of unarmored ships." The number of vessels in the fleet would be regulated by the services they have to do and the ships they are likely to meet, not by the relative cost of their antagonists.

To make the cost of your adversary's fleet limit the efficiency of your own would be worse than accepting for your guidance the narrowest views of the very worst school of commercial economists, who, by reducing the price of their manufactures to induce purchasers, have in many cases ruined the trade of the country.

And, again, after describing an imaginary contest of three cruisers and one iron-clad, it is most remarkable that the result of "fleet fighting" should only be referred to in order to be dismissed without examination, while, if past experience is to guide us, it is clear that it is the gist of the whole matter, and will have to determine the very existence of the nation in real and serious war.

But it is not from regarding the controversy from any such points as these that a reversal of the entire shipbuilding policy of the country can be successfully attacked.

The great aim sought to be accomplished by the introduction of armor-clad vessels was to enable a fleet to stand up the greatest time possible against the fire of her enemy's guns, and unless, or until, a case has been established showing that such a change has been effected in the relative power of the attack and defense as to overthrow the conditions that have previously existed, no case has been made out to warrant a fundamental change.

Now, I venture to think that nothing has occurred to warrant such a conclusion.

In both cases immense strides have been made. The introduction of long breech-loading guns has greatly increased the power of penetration and added to the power of attack; but steel-faced armor and steel hulls (instead of iron armor and iron hulls) have added equally to the efficiency of defense.

Steel-faced armor of similar thickness with iron will afford one-third to one-fourth more resistance, while the superior tenacity and ductility of the material will give it a further important advantage in resisting disruption, and thus, in most cases, restrict the damage that would result both to the ship struck and the crew inside it; while the same characteristic exists as to the ductility and superior qualities of the steel hull, and the additional strength it possesses enables the naval architect to reduce the weight of his ship and to improve his lines without diminishing the strength of the fabric.

I really believe that, instead of a case being established for the suppression of the system at present relied on, from the conditions on which it was based being overthrown, the result of the immense improvement in guns has been fully balanced by the corresponding improvements in the hull and armor to which they are opposed.

Now, the facts stated, the arguments adduced, and the conclusion drawn, all point to the conviction in Sir William Armstrong's mind that the functions to be performed by swift armed cruisers and the armor-clad fleet are the same, whereas the service required from them is distinctly and altogether different; and in practice I venture to think it will be found absolutely impossible with cruisers, however numerous, to perform the service for which the iron-clad fleet is specially required.

Cruisers will be specially adapted and properly employed in protecting and convoying our commerce, keeping open the seas to enable our merchantmen to trade without interruption between the principal ports whence we draw supplies and our shores, lending naval assistance to our colonies when needed, and performing many similar secondary services; and it may be freely admitted a very large number of them are required for such services beyond those we have or are even contemplating building; but they will be wholly unfitted to fight in line of battle, and stand up against an armor-clad fleet, where endurance alone will determine the result of the encounter, and where the endurance of the iron-clad fleet may be reckoned by hours against minutes on the part of the unarmored cruisers, even if they elected to oppose the fighting fleet at all, for really, beyond possessing great value for guerilla warfare, no decisive victory could be obtained or even hoped for against an iron-clad fleet by vessels whose safety, when hard pressed, would only be secured by their running away.

The functions of the iron-clad fleet would be, to attack in line of battle the enemy's fleet, wherever found; to drive it from our shores and home seas; to follow it, and confine it to its own harbors; to maintain an unchallenged command of the sea routes leading to our coasts; to protect our great naval arsenals against the enemy's fleet; and to oppose all attempts, under cover of the enemy's fleet, of the landing of troops for invasion at any point of the coast; so that the cruisers might be safely left to convoy or protect our merchant fleets, and enable them to perform the indispensable duty of bringing us uninterrupted supplies.

To perform these services efficiently, and in opposition, not to one nation only but to any combination that may be considered possible, will no doubt require such an augmentation of our fleets, armored and unarmored, as will cause some very special arrangements in the budgets of the chancellor of the exchequer for five or six years to come. But this is by no means a reason why the most important duty that the executive and Parliament have to face should be avoided.

In olden times the duty of maintaining our navy equal to any combination that it might be called on to face and overcome was accepted and provided for.

Of late years we have been particularly remiss in adding to our fighting ships, mainly from the mistaken idea that as the rate of improvement was so rapid, the money spent on building vessels that might become obsolete would be wasted; while foreign nations have all been specially active in increasing their fleets; and should any catastrophe occur before we have resumed the commanding naval position we have for centuries maintained, the responsibility we shall have incurred by following this course will be most serious—the loss to the empire irremediable.

The money difficulty, that appears so prominently in Sir William Armstrong's arguments, really sinks into insignificance when the magnitude of the issues involved are realized. The simplest way of regarding this portion of the subject is to treat the cost necessary to produce and maintain our navy in the highest state of perfection and of most undoubted strength, as an insurance against the loss which invasion or defeat would impose. Sir William Armstrong's warning on this head is most significant; he points out there is no country so likely to excite the greed of an assailant as our own, or so vulnerable in relation to commerce; that war indemnities have degenerated into mere exactions proportioned to the wealth of the vanquished; and England, being the richest of nations, offers the highest premium for successful attack.

These observations should be taken in conjunction with the practical result of the Franco-German war, during which the inhabitants of the French chief city were for months suffering all the pangs of starvation, and after capitulation had to pay 200,000,000 sterling by way of indemnity (a sum believed to be beyond the power of the country to procure), but which no doubt would not equal one-fourth what would be required of England, the richest nation in the world, in similar circumstances.

If, therefore, for some years to come, the yearly additions to the navy represented two or three millions of money more than at present, they would not equal one-half per cent. insurance on the penalty we might expect to have to pay if, through our deficiency of naval power, we were to suffer defeat at the hands of any combination of powers.

Such a national misfortune must be avoided at all cost, and I hope the effect of this discussion will assist materially to convince our naval authorities, and through them the House of Commons, that, instead of discussing the suppression of iron-clads, a maintenance of their present policy and a great increase of both classes of vessels, iron-clads and unarmored cruisers, will be considered indispensable for securing the position that the country has possessed, and the prosperity that has resulted from it, from time immemorial.

DISCUSSION.

Admiral Sir Geoffrey Hornby, K. C. B. My lord, I came here solely for the purpose of instruction, unprepared to speak on this or any other subject in the paper; but being called on in this way, I can do nothing less, in the interests of the service and the country, than thank Mr. Samuda heartily for the paper he has read, in the principles of which I entirely concur. I read Sir William Armstrong's paper with great interest, and with that respect which every officer in the navy must feel for a person of his extraordinary talents; but I entirely differ from the conclusions to which he came, as to the possibility of unarmored ships contending, I might say in almost any form, with armored vessels, for this reason, that it goes against a first principle of war, which is, that a concentrated force will always prevail over a force that is spread. An iron-clad ship represents concentrated force, the concentrated force, if you like to take it in money, which is divided between the three cruisers. I am sorry, in explaining what I have to say, to have to go into details, which perhaps the paper suggested should not be gone into. The view I take is this: that you may put an ironclad in any position you please, and if she is attacked by three of these vessels she will make a run at one vessel or the other, attack her with her guns, and threaten her with her ram, and it must be death to that vessel if she touches her any way. The two other vessels, you say, will follow and disturb the action of the iron-clad; but it must be recollected that the iron-clad will always be firing at them, one gun at least, and with shells, the bursting power of which must necessarily, as far as we know, destroy the fighting power of the cruiser. If any one contemplates what the bursting of a shell filled with 37 pounds of powder in the center of any unarmored vessel would be, I think he will agree there would be no more fight left in the ship. It is no answer to say that the ship is armed with a gun as heavy as the iron-clad has; the *morale* of the people will be destroyed, and they will be unable to continue the action against the concentrated force to which they are opposed. For that reason I hold that the unarmored ship cannot contend against the armored. As to the point on which Sir William Armstrong based his proposal as to the money question, that is a matter I do not think it is the part of any naval officer to discuss; it is a matter for the statesmen of the day. I think I am only saying that which every naval officer will support me in, that we contemplate with dismay the result that might accrue from having the supplies of food of this country shut up, as was the case with the great city of Paris, by a force which, without subjecting the country to be fired on, must cause it to submit, as Paris did, from starvation. What the money cost alone to us might be, independent of other things, is a matter every one here can guess. I only say on first principles of war I think the iron-clad is a vessel to which we must adhere, and that a number of unarmored ships costing the same money cannot in any way be made successfully to take its place.

Captain NOEL, R. N. I rise with great hesitation before such a large assembly of scientific men, but there seems to be rather a slackness on the part of members addressing the meeting. My lord, I wish, in a humble way, as a naval officer, to support most strongly all that Mr. Samuda says. Our highest naval authority could not have described the requirements of the navy more thoroughly. The question of the duty of iron-clads and cruisers is one which we do not often have the opportunity of discussing; but Mr. Samuda has put it before us in as clear and concise a manner as the most experienced naval officer could possibly have done. I especially agree with him in these points; there is no doubt about the necessity of our having an armored fleet—of all other countries in the world England must have an armored fleet. Mr. Samuda has told us its duties, and those duties are most onerous. Then next, we require cruisers of considerable speed. In that respect I am afraid we rather fail. Speed at one time, in the early wars of the beginning of this century and the end of last, was thought so necessary for the smaller vessels, that every frigate had the speed of a larger ship; *brigs* had the speed very often of the frigates. In the present day the speed of our cruisers is, I am sorry to say, not what it ought to be. The C class of steel cruisers we hear so much of do not come up to the speed of the armored vessels, and if they are met at sea by these armored vessels they have not got the heels of them, so as to escape; I think that this is an exceedingly important point. As to the general increase of the strength of our navy, I am certain that every naval officer will fully concur in what Mr. Samuda has said; indeed, the whole country should know how we stand in this respect. There is a curious statistic which I only made out the other day. In 1866, just after the first flush of iron clads, we had built more than any other nation; we possessed at that time a total tonnage of armored vessels amounting to, roughly, 180,000 tons. The tonnage of the armorclads of the rest of the world at the same time was only 240,000 tons, which, as you will see, is very little more. At present (it is rather difficult to find out how far certain iron-clads are advanced) the numbers are somewhat these: England has 380,000 tons of armored vessels, against the rest of the world 900,000 tons. I take it this shows that as far as armored vessels are concerned the rest of the world is walking two to one faster than we are. As a general question there is no doubt that this is a very fair way of looking at the naval power of nations. Other vessels are not in the same category; as Admiral Sir Geoffrey Hornby has shown us, it is impossible to pit an unarmored against the armored vessel. I am opposed to vessels of very large dimensions. I think in the present day too much individual cost is a great risk. In the first place, torpedoes will play a great part in our coming actions, and we know the larger the target the greater the danger. Although you can make her fairly safe against one or two torpedoes, yet in an attack like what you might have in the present day of thirty or forty of these swift torpedo boats on a blockading squadron, the largest iron-clad might be blown up. Therefore I think our advice should be to keep down size. I am also opposed to carrying very heavy guns, because you can only carry so few of them, can only fire them at considerable intervals, and there are so many disadvantages on an ever-moving platform, such as we have in any ship, that you would be very liable to miss. I prefer to see a larger number of guns of moderate size; in fact, I quite agree with Sir William Armstrong, that in most naval questions there is a good deal of moderation required. Now, as regards armor, I think a good deal of evidence goes to prove that a small thickness of armor, especially if the armor is steel-faced, is of considerable value. In manoeuvering a vessel not particularly well defended with armor, you would naturally manoeuver so as not to present your broadside more than you could help to the enemy, and a very ordinary thickness of plating would cause a shot to diverge. Armor, I take it, should protect the vital parts of the ship, should be concentrated on the vital parts. There is no such need now of protecting your guns and crew; you have the ram and the torpedo, and you can replace your crew. Your object should be to build a ship so that she should not be sunk. Sir William Armstrong tells us it is very difficult to sink a vessel, whether she is armored or not, with guns. Well, that may be the case, but if a vessel is unarmored, she is first injured by those guns, and then she is sunk. It is difficult to sink a vessel with guns—we know that perfectly well—but it is not so difficult to injure her. If you injure the ship, or even if you can fill her bow compartments and check her speed and steering power, then she is rammed. It is the injury you must guard against, and that you can only do with armor. As regards the cost, I ought, perhaps, not to say so here, but among the general public it is a misleading statement to make, as Sir William Armstrong did, "that we could have three unarmored vessels for one armored vessel." As a matter of fact, as no doubt most of the gentlemen here know, the cost of actually building iron or steel cruisers, including engines, is almost the same, ton for ton, as that of armor-clad ship. According to Sir Thomas Brassey's book, the *Iris* exceeds in value, ton for ton, anything we have yet built; the *Bacchante* is about the same as the most expensive iron-clad; the *Alexandra* is one of the most expensive iron-clads, and after that comes the *Agamemnon* and several others. Even the C class of corvettes costs as much as most of the iron-clads per ton. I am afraid when you speak of a cruiser costing only one-third as much as an armored ship it is not strictly the fact, unless it be that she is only a third of the tonnage. I think too many thanks cannot be given to Mr. Samuda for bringing this paper before the institution and the public, and I can only hope that our members of Parliament will read and digest every word he has said.

Mr. N. Barnaby, C. B. My lord and gentlemen: It will be very readily understood that I have not been able to agree with Sir William Armstrong, any more than Mr. Samuda has, in the statements of the paper which he gave to the Institution of Civil Engineers. I think that the statement that unarmored ships can be protected against being overcome by guns as readily as armored ships can be, if I may put his statement in that form, cannot be supported. He speaks of the power of coal to take the place of armor. I have had a good deal to do with that, but I have never considered that coal could take the place of armor in regular fighting ships. What I have said has been, that I believe coal can be made to give the protection which the merchant ship so much needs, if you are going to make any use of her at all; but I believe it is a complete mistake to suppose that you can make a ship unprotected by armor other than most vulnerable to the gun. I do not mean to say that you could not so divide her that it would be a long time before she could be sunk. As Captain Noel has said, that is one thing; but the other thing is this—she can be disabled, and disabled quickly. You may, by putting shell in the right place on one side of a ship, make her heel most dangerously, and in that case she becomes helpless. Until some one has produced an unarmored ship which we can be invited to go and look at, as being a ship that cannot be sunk by guns, I must hold myself free from any agreement with a statement of that kind. I do not believe it can be done. I know pretty well the ships built for fighting purposes without armor, and I believe no defense can be set up for them, on the ground that they could be made to resist the gun in anything like the same way as a ship protected by armor can be. The next point I wanted to mention was Mr. Samuda's statement, that "the great aim sought to be accomplished, by the introduction of armor-clad vessels, was to enable a fleet to stand up the greatest time possible against the fire of her enemy's guns, and unless, or until, a case has been established, showing that such a change has been effected in the relative power of the attack and defense as to overthrow the conditions that have previously existed, no case has been made out to warrant a fundamental change." Now I think it is necessary, in order to take that position, that you should really face the difficulty of the change which has taken place since armor was introduced. A very great change has occurred. The introduction of the torpedo and of the ram has very greatly modified the condition, and those people who regard most seriously the power of the Whitehead torpedo, talk about the gun rapidly becoming as obsolete as bows and arrows. Therefore, you cannot say that the arguments of people like Sir William Armstrong have no foundation, until you have really made up your mind as to what the torpedo and ram have done to make the ship, even although she is covered with armor, capable of being overcome by small fast ships. There can be no doubt whatever that large and costly ships may be sunk by lighter vessels, costing much less money, by means of the ram or the torpedo, if they have luck or if they are very happy in their attack; and then comes in, rightly, I think, the question of cost. I do not see why you should not look at the question in the aspect of a given sum of money having to be expended in placing yourself on fighting ground. If you say that there are certain parts of the necessary duties to be performed, which can only be performed by certain ships, then, of course, so far as those ships are concerned, it is no use looking at the money—you must have them; but it is not clear to my mind that that can be established. I hope I have spoken clearly as to my belief in the value of armor; at the same time, I cannot shut my eyes to the arguments of those people who point out how vulnerable a ship has become under water, and point out what high speed you may be attacked with, and if you are attacked in numbers what great risk the ship runs of being unable to keep afloat; and then, if you have put a ship costing £700,000 or £800,000 in the presence of an enemy that has only cost half the money, and he has a chance of sinking you by these weapons, then I think you can hardly be justified, without examining carefully your position, in going on indefinitely increasing the number of those very costly ships, instead of looking to the advantage you may get by putting your money into vessels protected in a certain way, but not armor-plated—there is a difference between the two—and having high speed. There is one other point I wanted to mention, that is, that people want thick armor, want it everywhere, want a number of guns, and a great many other things which, perhaps, are not passing through your mind at this moment as they are through mine. She must be capable, not only of Channel warfare and Mediterranean warfare, but of going to any part of the world, and she must have, in addition, great fighting qualities and high speed. Then, they say you must have a small ship; but I say it is hopeless to talk, you cannot do it. I say, boldly, this, that if you give me 10,000 tons with which to make a fighting ship, for every 100 tons you give me beside, I can make you a better ship. You can go on as far as you like. I do not know where I should stop. As you increase the size of the ship, you increase her resistance to being sunk, you increase her speed. You could increase her armor, her guns, and every single element of offensive and defensive power as you increase her size; the only limits are the limits of entering your ports, harbors, and docks, and the draught of water. Those are the limitations. Outside those, it seems to me, the objection to large ships, unless you take the question of cost, is a wrong one. I should like to give an illustration, not quite to the point, but touching it, from a vessel referred to this morning by our noble chairman, the *Stirling Castle.* The *Stirling Castle* is a ship for which those concerned in building her deserve the greatest credit. I look on her with much satisfaction from every point of view. She is a ship 420 feet along the water line, and probably of about 8,000 tons displacement—I do not know quite what it was—and with about 8,400 indicated horse-power. With that she did over 18 knots, say 18½ knots—I do not know precisely the figures—on the measured mile. We have in Her Majesty's navy a vessel, called the *Mercury*, which contrasted with her somewhat unfavorably. The speed of the *Mercury* on her runs was 18¾ knots. Look at the difference in the conditions under which those two ships are built and worked. The *Mercury*, for reasons which will be appreciated by naval officers, is only 300 feet long, and not 420. It is not, I think, the form of the *Mercury* that is in fault as compared with the form of the *Stirling Castle*; but because she is a smaller ship. The *Mercury*, with a displacement of less than half the *Stirling Castle*, 3,700 tons, requires 7,500 horses to give her her speed. That is, in the smaller vessel the number of indicated horse-power is about twice the number of tons weight of the ship, whereas in the *Stirling Castle*, 120 feet longer, you have only a little more than one horse-power for one ton weight. That is an illustration of the gain you get in big ships as compared with little ones. Any gentleman who should find fault with what has been done in the *Mercury* and *Iris*, should justify himself by showing us a vessel, not bigger than the *Iris*, which has done better.

Vice-Admiral DE HORSEY. My lord, as a naval officer, I do not like to let this discussion pass without tendering my thanks to Mr. Samuda for his paper. I think all of my cloth in this room will feel that he has done service to the nation. I speak with some hesitation after one of the first men in our service, Sir Geoffrey Hornby, who has put forward everything I could have said with so much greater force. The question of armor-plated ships against unarmored is, to my mind, not one capable of discussion. I can merely say I consider an unarmored vessel to be scarcely a man-of-war, or, I should say, scarcely a fighting ship. From what experience we have, if the non-armored ships meet the armored, if they are anything approaching the same size, no combat could take place. There is one point more, on which Mr. Samuda is a very much greater authority than I can presume to be, but still I think it requires some explanation. I think he said that an armored ship can be made to attain the same speed as an unarmored; that is to say, that a ship, say, with 1,000 tons additional weight, can be propelled at the same speed as another ship without that 1,000 tons.

Mr. J. D'A. SAMUDA. Will you repeat that?

Vice-Admiral DE HORSEY. I think Mr. Samuda said that an armored ship could be made to attain the same speed as an unarmored. Size for size, that seems to me to be impossible.

Mr. J. D'A. SAMUDA. That is exactly what I did not say, size for size.

Vice-Admiral DE HORSEY. Then it comes to this, that the armored ship must be larger to attain the same speed. There I cordially agree; but taking ships of the same size, I think we shall always find the unarmored will, or ought to, excel in speed, and we must not expect the armored ship, however desirable it is to have speed in her, to vie with the other in speed, size for size. The question of doing away with armor has been urged on account of the difficulty of putting sufficiently thick armor to keep out shot, but I think it has not been sufficiently considered that the shot and the vessel are hardly ever at right angles, and that there is no comparison between firing at a vessel at sea in action and at a target. The moment you deviate the least from right angles, away goes your shot anywhere. If your shot strikes the water short of the ship, if only 12 feet, that shot will not ricochet into her, but will go nearly straight up in the air, and over her (for the armor-plated ship is, as a rule, low). Cases are so rare in which an armor-plated ship exposes her side at right angles to your shot, that you may be content to have a little armor, and be very thankful for it. The experience that I can submit to the meeting of what I have read and seen in the Chilian and Peruvian war, is simply that the unarmored ships could not show their faces.

Mr. J. D'A. SAMUDA. The result of the discussion, so far as it has gone, to me at least is perfectly satisfactory. I am delighted to have had the opportunity of hearing such an expression of opinion as has fallen from Admiral Hornby, Captain Noel, and just now from Admiral de Horsey. There is only one point as to which I think my paper left a wrong impression upon Admiral de Horsey's mind, and that I would like to make quite clear. As reference has been made to the real object that the paper had, one of those objects was to caution people generally not to accept money as an element in the controversy at all. The absolute necessity of doing the work we have to do is that which should lay itself to the heart of every man engaged in carrying it out, and no matter what it costs. I wanted to show that you cannot pay too highly for that which is efficient and does your work thoroughly. The discussion here to-day has been most gratifying to me. What fell from Mr. Barnaby will go to answer the question asked by Admiral de Horsey, which is this, that if it is necessary to have a speed, which I believe it is, in your armored vessels similar to that which you may have to oppose in cruisers, if they are to be opposed to you, it is only an engineering question as to giving it, as Mr. Barnaby has pointed out to you. In increasing the size of your vessel you increase its efficiency. I want to get rid of the question of money altogether. I think nothing entered so completely into the erroneous conclusion that is drawn in this most admirable paper of Sir William Armstrong as the question of money, and as that question is, I believe, the *bête noir* of all the decisions come to with reference to skimping the amount of work that is to be voted in the House of Commons, I want to show that if efficiency were once attained, the cost would be more than ten times repaid by the saving that would come to the nation by averting a defeat. There is one point I should have been very glad indeed if Admiral Hornby or Captain Noel had dealt with, for I believe that to be equally essential; that is, the necessity of dealing with the *fleet fighting* that would take place. Because, even taking the view of Admiral Hornby to be sufficient to show the incompleteness of the argument that three cruisers could act against one ironclad, that by no means represents the enormous difference that would have to be made if our nation determined to confine its fighting ships to unarmored vessels, and had to oppose another fleet with armored vessels. You could not perform the same evolutions with fleet fighting, and where you have to meet your enemy in line, and stand up to him until one or the other is destroyed; it would be perfectly impossible. Even in the advantageous position spoken of in Sir William Armstrong's paper of a duel between one ironclad and three unarmored vessels, they could not steam round and round and fire, and hope to do anything under those circumstances. If, instead of being opposed to one ironclad only, two fleets having to fight for the supremacy of the sea had to combat in line, the inferiority of the unarmored vessels would be conspicuous. Therefore, I believe the expression of opinion generally goes to confirm that of my own, that it is absolutely impossible in the present circumstances that you can alter the general policy on which the shipbuilding of the country now exists.

The President. I am sure you will permit me to convey to Mr.

Samuda your thanks for his extremely able and interesting paper, and to those eminent naval officers, among whom we count one of our most eminent naval officers at this moment, Admiral Hornby, for their valuable additions to this discussion. I apprehend, if I may gather the feeling of the meeting, that what they would like to see would be a sufficiency of both types, of the armored vessels for the first line of battle, if I might say so, and the unarmored swift cruiser—that we should have both supplied in sufficient numbers. But then we come to the sufficiency of the numbers, and I am very much afraid, in spite of all the good advice which has been offered, having had twenty-seven years' experience of the House of Commons, that money will always be a prevailing consideration to its mind. That is the real difficulty. If you can persuade the House of Commons at any cost to provide us with money to build the ships, then the House of Commons must be composed of different materials to what it was when I was in it. I am sure you will allow me to convey to Mr. Samuda and those gallant officers who have spoken upon the paper our thanks. I think the fact of the discussion having been so short justified me in expressing the hope that we should get more naval officers to join us.

ON MODERN MERCHANT STEAMERS.

By JAMES DUNN, Esq., Member.

[Read at the twenty-third session of the Institution of Naval Architec's, 29th March, 1882; the Right Hon. the EARL OF RAVENSWORTH, president, in the chair.]

During the last few years I have been brought, in the course of my official duties, into constant communication with the owners and builders of the merchant ships of this country. And it has been suggested to me that, without disclosing any information respecting individual ships which has been obtained for the confidential use of the admiralty, and without in any way drawing conclusions which might erroneously be looked upon as official, it might yet be of service to you if some of the facts concerning modern steamers which I have in the last few years acquired were brought before your notice in the present form.

In the period of which I wish particularly to speak, there have been changes in our mercantile marine which must be within the knowledge of every person who is in any way brought into contact with shipping matters, or, indeed, of any intelligent reader of the daily newspapers. But there have been other changes which, though perhaps but partially known to you, and almost unknown to the general public, may yet prove to be of the highest importance.

Of the general effect of these latter changes I do not propose to speak. It will be sufficient for me to place before you, in as simple and complete a form as possible, of what these changes consist; and I do not doubt that from them the members of this institution will be able to draw, far better than could I, conclusions of interest to themselves and of benefit to the country.

The changes in our mercantile marine from sail to steam, from wood to iron, and, to a less extent, from iron to steel, are, I say, known to every one.

And equally evident is the growth of our commerce and carrying trade, both in absolute magnitude, and in relation to those of other nations. But it is very difficult to realize how great these changes have been.

In 1850, only 12 per cent. of the effective tonnage (*i. e.*, carrying power) of our merchant navy was steam tonnage; in 1880 the steam tonnage amounted to 62 per cent. While the carrying power of our sailing ships had increased less than 60 per cent. (which increase, moreover, occurred almost entirely in the first ten years of this period), the carrying power of our steamers had increased 1,750 per cent.

For several years past there has been a general diminution in the number of sailing ships owned and employed by this country. This diminution has occurred in sailing ships of all sizes with one striking exception. There has been an increase of about 50 per cent. in sailing vessels of 1,400 to 2,000 tons; and as sailing ships of this, the largest size, are still being extensively built for the White Star and other large firms, it seems likely that it will for some years be possible to economically use such vessels on long distance trades. With this solitary exception, the transfer, first of the general passenger trade, and later on of the general cargo trade, from sail to steam is now nearly complete.

As regards the material of which our ships are built, in 1880 only 20 per cent. of the tonnage built in the British Empire was wood, and less than 5 per cent. of the tonnage built in the United Kingdom.

But this change from wood to iron appears to be a step and nothing more. Iron is being replaced by steel in the same way.

There were 21,000 tons of steel shipping built in 1879, 36,600 tons in 1880, and 45,000 tons in 1881. We have had the efficiency of steel steamers very thoroughly discussed by Mr. Denny, and the East coast ship-builders; and there seems little doubt that in the long run the question will be generally decided in favor of the best material.

Then, as to the work done by these ships; the entrances and clearances of British ships in the foreign trade at ports in the United Kingdom increased from 9,500,000 tons in 1850 to 41,500,000 tons in 1880, being about 340 per cent.; and whereas in 1850 one-fifth of this tonnage was steam, in 1880 steam formed three-fourths.

Other countries have largely increased their trade and shipping during the last thirty years, but not at so great a rate as this. The carrying power of foreign nations has increased by 250 per cent., but ours by 380 per cent.

The value of British shipping is now estimated to be one hundred and fifty to two hundred millions sterling.

Remarkable progress has been made in certain trades. Take the direct trade between England and the Atlantic ports of the United States. From 1850 till 1862 two-thirds of this trade was done by American shipping. In 1865 the American share had fallen to one-quarter of its amount in 1862, and in 1880, although the gross trade is three times as much as it was in 1850, only one-fourteenth of this trade was done in American, and seven-ninths in British vessels.

Take, again, the East India trade. The trade carried on by foreign vessels is about the same as it was twenty-five years ago, but the trade in our own vessels is seven times as much as it was then.

Over four-fifths of the tonnage passing through the Suez Canal is British. I may notice, incidentally, that the size of the steamers using the Suez Canal increases very slowly. Between 1874 and 1880 the total tonnage passing through doubled; the average tonnage only increased about 10 per cent., although in the mean time a large number of very large vessels had been built expressly for the work. There is, of course, the limitation of draught, but it is more likely that the large new steamers are swamped by the great number of smaller cargo steamers lately sent through the canal on account of slackness of trade in the Black Sea and Mediterranean.

Looking to the immediate future, we may reasonably anticipate that we shall retain our share of the carrying trade of the world. Each change of the conditions of trade appears to operate in our favor. Goods as well as passengers are now carried in steamers, and more and more in large steamers. Every effort is made to decrease the time as well as the cost of transit. And this seems likely to be best effected by continuing to increase the size and speed of general cargo steamers. The increase of size and the transition from sail to steam take place more rapidly in British than in foreign vessels. We have the great advantage of building all our own steamers and 60 to 70 per cent. of the foreign steamers. And so we are likely for years to come to have the benefit in peace, and the responsibility in war, of most of the carrying trade of the world being conducted under our flag.

The above figures set forth, what you will all agree to, that our trade and shipping have wonderfully increased during recent years. It appears, moreover, to be agreed by all—all, at any rate, whose remarks I have read or heard of—that this great trade will be a very vulnerable point in any future war. That opinion has been very strongly put by American naval authorities, and it was evidently the belief of the Russians in 1878. I am extremely anxious to avoid offering any speculations of my own upon this subject; they would be of small intrinsic value, and they might be misconstrued. But the opinions and conclusions of those among you who are best able to speak with authority will be necessarily founded on a full inquiry into and an acquaintance with the facts of the case. Such an inquiry would embrace not only the extent of our merchant marine, our over-sea food supply, and our foreign and colonial trade, but also the resources which are available to defend these interests.

It would, therefore, include a knowledge as to what part of our regular navy would, after reserving sufficient strength for home defense, and for opposal of such hostile fleets as we might fairly be expected to meet, be at the disposal of the Government for this special work, and of its fitness for performing it. It would include an estimate of the extent to which, if necessary, this force may be increased, and, when required, manned. It would, further, include a knowledge of the extent, if any, to which merchant steamers could be used for their own defense, or the defense of their fellows, of their individual fitness, and of the number available for such work.

I do not say that these, and these only, are the facts with which you should be familiar that you might pass a sound opinion on the question; but looking to the fact that it has, on the one hand, been held desirable to very largely increase our royal navy, under the belief that merchant steamers are unfit for fighting, and that, on the other hand, it has been thought that merchant steamers would make such excellent cruisers that the existence of such a class in the royal navy is unnecessary, I imagine that it is not presumption on my part to say that a full inquiry into the above matters is necessary, that you may form a reliable judgment on the general question of the defense of British interests on the ocean.

It is unfortunate that while the opinion that the cruising vessels of the navy should be multiplied in number to meet these requirements seems to be sometimes held, no detailed scheme for providing and maintaining such fleets, or for manning them when they were provided, has been presented to the public by the supporters of this view. And pamphlet-writers generally confine themselves to depreciatory remarks as to the cost, the slowness, and the limited coal supply of our regular cruisers.

I am unable to put before you, therefore, any information on this side of the question; but I have seen very much of merchant steamers during the last six years, and during that time many changes have occurred, which, though they have mostly come about for strictly commercial reasons, have undoubtedly affected, in a remarkable degree, their capabilities for modern fighting. To these changes your attention is now asked.

First, take the question of speed. We are principally interested with vessels of the highest speeds and of considerable coal-carrying power. Between 1875 and 1882 the number of steamers having ocean speeds of 13 knots and upwards has increased from twenty-five to sixty-five. Of these there were only ten of 14 knots' speed and upwards; now there are thirty-five. The highest speed was then 15 knots; now we have several steamers with speeds approaching 17 knots.

This increase in speed of many first-class steamers is all the more important, because the average speed of merchant steamers has not advanced at a corresponding rate.

Take, again, the question of coal endurance. The gradual improvement of marine engines has brought about a considerable increase in the power of cruising, or steaming for long periods without recoaling. The effort made to secure economy and success in mercantile trade has directly increased the fighting power of merchant steamers. We have now many steamers which can carry sufficient coal to steam round the world at a 10-knot speed, and these steamers are of moderate dimensions. There are ten such vessels on the Cape mail service, and four others building. None exceed 380 feet in length.

In a lesser degree the fighting value of merchant ships has been affected, in that their structural strength has considerably increased. This has been largely due, in the matter of longitudinal strength, to the investigations made during the last ten years, and communicated to this institution, and to the great care of Lloyd's surveyors. The improvement in the quality of iron and in the modes of working, the use of steel, the introduction of double bottoms, and the more general employment of complete iron and steel decks, have all helped in this direction.

The question of structural strength has frequently been raised when proposals have been made to fight guns in merchant steamers. The Admiralty Committee of 1852 thought that they would require strengthening, and doubts as to their strength have been expressed in this institution. A direct experiment, however, was made in 1878 on this point. The Admiralty purchased the *Hecla*, then building at Belfast for the Atlantic trade. Without any additional strengthening she was armed with five 64-pounders and one 40-pounder, on truck carriages, and such fittings and stores as would be supplied to merchant steamers were placed on board. The vessel was then sent on a trial cruise with a complement of officers and men from the royal navy. Admiral Boys and the officers reported very favorably of her, and, although she was not so handy as the ships to which they were accustomed, and as are other shorter vessels in the merchant service, the experiment was a decided success. The *Hecla* has been in commission ever since.

Heavier guns than the 64-pounder were placed on the steamers bought by the Russians in 1878, and an Irish cattle-boat, in the hands of the Chilians, was armed with an 8-inch 11-ton gun, and was employed in the bombardment of the Peruvian ports.

In the next place, there is the question of water-tight subdivision.

It was soon found out, on the introduction of iron shipbuilding, that a hole can be much more easily made in the bottom of an iron ship than of a wood one; and, as there is very rarely sufficient pump power* to keep the leakage under, it follows that, if the bottom is exposed to even feeble local blows, an iron ship is much more easily sunk than a wood one.

In war steamers, therefore, the practice of dividing them into a number of water-tight compartments by iron transverse bulkheads was early resorted to; and by having in addition, double bottoms, water-tight flats, &c., these compartments have been increased in number till, in some of our recent ships, there are more than one hundred. Many of these might be filled and the ship would still float.

But respecting merchant steamers there has been an extraordinary amount of apathy. Vessels collided, one or both received some slight damage, foundered in an hour or two, perhaps in much less time, and the result seems to have been regarded as inevitable. And I believe that most people still think so. Every few months a bad case of collision occurs, perhaps with great loss of life, and the newspapers almost invariably remark that there is a fresh proof that water-tight bulkheads

*In some of the latest mail steamers very powerful pumps have been fitted, but the above statement is still substantially true.

are of no use in an emergency. It generally happens that the vessel in question sinks for want of them. Or if they vary their comment they say that there ought to have been more boats, or perhaps another pump. I am of opinion that if one-half of the ingenuity and perseverance displayed in devising means of preserving life in case of a ship foundering were devoted to keeping the ship herself afloat, we should attain far better results.

Now, I think it will not appear to you to be asking for an unreasonable amount of subdivision to say that a steamer ought, under ordinary circumstances of weather, lading, &c., to be free from the danger of immediately foundering after collision with another vessel. You cannot, of course, say that safety in collision shall be absolutely guaranteed. A bulkhead may itself be damaged, the ship may be already very deeply laden, or with her altered trim she may be unseaworthy, and succumb to stress of weather; but these are additional and rather remote risks, and ought not to prevent us from saving the ship when none of these further dangers occur. It surely may be granted that a ship ought not to be allowed to go down in a few minutes, when two or three bulkheads would prevent her sinking at all.

So far was this from being the case, that there were a few years ago only thirty or forty large steamers in the country which could, even with great leniency of judgment, be said to be so built. Lloyd's rules insisted on a bulkhead at each end of the ship, and one at each end of the machinery space.* And if you build a ship with four bulkheads only, this arrangement is probably as good a one as could be made, but in case of collision between two such vessels, only one of these bulkheads was generally of any use. The ship struck was almost sure to founder, but the striking ship was saved by the collision bulkhead, so that this arrangement might almost be said to offer a premium on running down a vessel which got in unsafe proximity to your own.

In examining the loss of life and property at sea, the small amount of life (compared with property) lost by collisions is mainly due, I believe, to the collision bulkhead saving the striking ship. The vessel struck founders almost at once, but her crew either jump on board the other steamer at the instant of collision, or are picked up shortly afterwards.

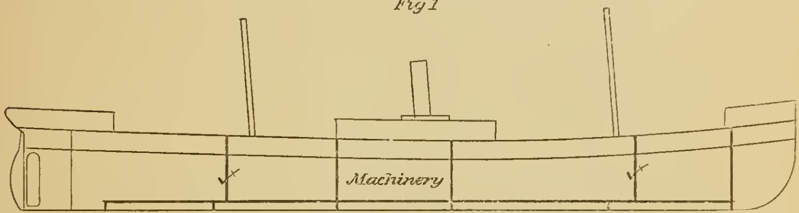
Now while this arrangement saves one vessel, two other bulkheads would save the other. Take a steamer of the most common type, a medium-sized cargo steamer (Fig. 1). She is compelled to have the collision bulkhead. She must also have two more, which bound the engine room, though these are sometimes not water-tight. It is then only necessary to make them so, and put in two other bulkheads as

* There has been recently added to Lloyd's rules a recommendation that, in steamers 280 feet long and above, an additional bulkhead be fitted in the main hold extending to the main deck. It is to be regretted that Lloyd's have not gone farther in this direction.

shown in the diagram, and you will insure, in ordinary cases, the safety of the ship.

Something of this kind was frequently attempted in merchant steamers, especially in long passenger ships, but often in a very remarkable manner. The bulkheads were usually so arranged as to give the minimum amount of safety on the given weight of iron. In many ships the great care exercised in making water-tight doors in the 'tween decks was thrown away by cutting large open doorways in the hold. Bulkheads, with elaborate sliding doors in the hold, had their tops below the water level. Some vessels had as many as ten or twelve bulkheads, of which but one was of the slightest use in collision.

Fig 1



✓ Additional bulkheads referred to.

Good subdivision has been said to be impracticable, on account of the expense and the inconvenience of arbitrarily dividing the holds.

The best reply is that it is now very generally done. Even in 1875 there were large firms all of whose steamers were so built, and now there are no first-class mail steamers building which are not so constructed. All the passenger steamers built during the last three or four years for the Allan, Anchor, British India, Clan, Colonial Mail, Cunard, Guion, Inman, Monarch, Orient, Peninsular and Oriental, and Union Lines comply with the condition above referred to.

Many other companies own Atlantic cattle and cargo steamers, colliers, and passenger paddle river boats which are similarly built. These facts will probably be taken as conclusive of the question of the practicability of bulkheads in steamers.

The expense is small. One firm estimated it as £300 each for *altering* a fleet of mail steamers. But the cost of introducing them while building, or in many cases of merely arranging them so that they shall not be useless, is much less. And I imagine that very little extra cost is involved in inserting in the contract, as is now generally done in these cases, that the ship is to be built with bulkheads to meet this condition. The loss of money due to one large vessel sinking would pay for this extra work in three or four times as many ships as are yearly registered.

A very long saloon is the greatest difficulty met with, but long saloons with cabins at the sides are otherwise objectionable, and are being discontinued.

In cargo steamers it is evident, on looking at the diagram, there is no difficulty at all. You have the same hatches, the same winches, and the same stowage with bulkheads or without them, and the bulkheads confine local leakage and consequent damage to cargo.

There is one other objection I have heard. It has been said by eminent builders and others in this Institution that these bulkheads cannot be relied on. A few test cases may be interesting.

The *Agia Sofia*, 2,586 tons, owned by Papayanni & Co., was struck by the *Newton* while lying in the Mersey, with 2,300 tons of cargo on board, in September, 1880. She was cut down to 2½ feet below the water-line, but her bulkheads kept her afloat.

The *Anchoria*, 4,168 tons, of the Anchor Line, was struck by the *Queen*, 4,457 tons, 300 miles from Sandy Hook, in June, 1880. She was struck nearly amidships, and had 28 feet of water in the compartment, but her bulkheads saved her.

A similar case was that of the *British Queen*, of the Cunard Line, in the Mersey in 1867.

The *City of Agra*, City Line, was struck 8 feet abaft engine-room, by the *Nepthis*, at the mouth of the Mersey, in November, 1880. She was cut down to within 8 feet of the keel, but the bulkhead dividing the after hold, though damaged by collision, saved the ship.

The *Helvetia*, 4,588 tons, of the National Line, was in collision with the *Mona* in the Mersey, in January, 1881. She was cut down several feet below water in after hold. The compartment filled, but the bulkhead saved the ship.

The *Sutherland*, 959 tons, of the Leith and Hamburg Line, was cut down by the *Duchess of Sutherland*, going 14 knots, off Holyhead, in July, 1877. The after hold filled, but the bulkhead at fore end saved the ship, and she steamed into Holyhead.

The *Utopia*, 2,731 tons, of the Anchor Line, was struck by the *Merlin* in Febuary, 1878. Fore hold, 60 feet long, filled; but bulkheads kept the ship afloat.

There are many other instances of a similar kind, but these will be enough to show that bulkheads are structurally strong enough to resist the pressure of water upon them.

A large part of this paper has been taken up by the question of water-tight subdivision, but you will perhaps pardon this, in consideration of the very great importance of the change which is thus taking place in merchant steamers, both from a commercial and military point of view.

Another change is in the increasing breadths of many modern steamers. This has been largely due to those experiments which have shown that economical results are by no means confined to ships of excessive length. It is a change of great importance for three reasons:

In the first place, the shorter ships are handier ones; in the second place, they have presumably greater stability; and in the third place, the increase of beam makes it possible to place a block of coal of considerable thickness at the sides of those portions of the machinery which are above or near the water line.

In 1878, and again last year, some interesting trials were made of firing shells at loose coal, representing the bunkers of merchant steamers. The general result was that the thickness which can be got in ordinary steamers is sufficient to stop shells from the heaviest guns in general use in unarmored war vessels. And the greater beams now becoming common make it possible, with some thin loose armor plates, such as might easily be used in case of necessity, to stop shells even from the powerful 6-in. and 8-in. breech-loading guns of Sir William Armstrong. This increase of resisting power is an important consequence of the increasing beams of modern steamers.

A considerable change in the forms of modern steamers has come about through the explosion of the old notion that the form and area of midship section were all-important elements in economy of speed results. Steamers have no longer the great rise of floor formerly common, and have consequently greater cargo capacity.

In these alterations of forms, and in other matters, we are indebted to a considerable extent to those shipbuilders who have so wisely and successfully availed themselves of the results of modern science.

Then there is the very common use of double bottoms. They are of very great use in case of a vessel getting ashore—most of all when she runs over a reef into deep water. This is a case which transverse bulkheads may fail by themselves to meet.

The steering power of merchant steamers has been increased, not only by the adoption of more moderate proportions than those in use a few years ago, but also by the introduction of steam-steering gear. It might be still more largely increased by increasing the rudder area, which is still about the same as when hand-power only could be used. In that case the rudder posts would require strengthening, and this appears to be necessary even now, if we may judge by the frequent disablement of steamers through injury to the rudder posts.

The same results have been aided by the introduction of twin screws into our large merchant steamers. It is quite true that at present it has been only an introduction; but I hope that the three large twin-screw steamers built last year, and the two building now, will prove to be the commencement of a very general practice. That there is a serious drawback in the extra care required in docking, no one doubts. And many small cases of injury to the screws might occur; but they would occur where there is every means of repairing the damage, and not like accidents to single-screw ships, far away from port. Large and valuable vessels are now continually breaking down in mid-ocean by the failure of some part of their machinery. This will be practically impossible in a twin-screw steamer, and will save the expense of towing into port, of the consequent delay, and of repairing the ship away from home, or towing her all the way back again. Twin screws have given to war ships, and will yet, I hope, give to merchant ships, a practical immunity from the perils of machinery breakdowns in mid-ocean, and a reliable steering apparatus in reserve.

Summing up the foregoing statements, we have then:

1. The British mercantile marine has grown to an unprecedented extent, and has acquired a larger part of the trade of the world than it ever carried before. Each change in the conditions of trade has appeared to favor it, and our advantage is likely to continue for some while to come.

2. The best method of defending this marine in war time has been a subject of frequent discussion. And one element in the question is the fighting power of modern merchant steamers.

3. During the last few years important changes have occurred in merchant steamers. They have acquired—

1. Increased speed.
2. Increased coal endurance.
3. Greater structural strength.
4. Much better water-tight subdivision.
5. Improved pumping facilities.
6. Greater beam.
7. Double bottoms.
8. Steam-steering gear.
9. In a few cases, twin screws.

These are some of the chief changes which have occurred during recent years in modern merchant steamers. They have come about to a very large extent as the natural development of our merchant trade. In part they have been due to special effort. They have all improved the commercial value of the ships themselves, and, in that sense, have been of value to the nation. But they have, perhaps, been of almost equal importance in the degree to which they have affected the conditions of those problems which have so continuously varied during recent years—the naval defense of this country, and the provision for the safety of its merchant marine in war.

In this way I trust that a statement of facts, without any expression of my opinion on them, may be of interest to some of you, as being, to a large extent, the authors of these changes, and of service to the Institution as affording a basis for the discussion of a subject so interesting to all of us—the maritime strength and security of the British Empire.

DISCUSSION.

Mr. William Denny. My lord, I think we may all congratulate ourselves upon the extremely interesting and the very modest paper that Mr. Dunn has put before us, and I hope that the modesty of the paper will not mislead any of us as to the value of it. As a *résumé* of mercantile practice, it is of the very highest value. In it Mr. Dunn has shown a modesty not merely with regard to his own performances, but with regard to the influence of the Admiralty upon mercantile steamers.

The Admiralty, and especially Mr. Barnaby, may claim for themselves that in the water-tight subdivision of hulls they have revolutionized the merchant service. They sounded the first note of alarm upon that point, and they have since utilized the interest which they raised, in developing a right system of water-tight subdivision. Mr. Dunn has remarked that the division of a steamer's hull into many compartments involves some slight expense; but although it may involve expense, I am able to say from the experience of shipowners for whom my firm has built, that it involves also large conveniences. The steamers which trade between India and this country have now not only to do a service between terminal ports, but they have, further, to do a service between their owners' intermediate ports, and find it of very great value, instead of having large holds in length and capacity, to have holds in which they may place with ease the stowage for each separate port, and discharge it at once when they arrive there, without disturbing the stowage for the terminal ports. We may congratulate Mr. Barnaby and the Admiralty that they had not merely introduced a change into the merchant service which has been useful from a point of view of safety, but which has been useful commercially. To-morrow we shall have brought before us the question of freeboard, and it seems fitting that any paper upon the merchant service should be related as closely as possible to the great question of freeboard, now agitating the mercantile marine of this country. What the Admiralty have done has the very largest influence upon the question of freeboard. We know that Lloyd's committee, and I believe Mr. Rundell previously to them, introduced the idea of having surplus buoyancy as a measure of freeboard. Now, surplus buoyancy has several meanings, but in connection with this paper we may assume it has only one; that is, the meaning that in the case of a ship being opened up to the sea, either above or below, the greater your surplus buoyancy, the longer she will take to sink, and the greater chance you will have of saving life and steamer. But a steamer may have an enormous amount of surplus buoyancy, and for want of proper subdivision may sink perhaps before a quarter of that surplus buoyancy is brought into action. If you had a steamer without those bulkheads marked "B" (pointing), and you had either the fore-hold or after-hold pierced, that steamer would change her trim to such an extent that she would bring openings under water which were not anticipated, and you would find, long before your fancied surplus buoyancy had come to have any effect, your ship and crew would have gone to the bottom. Therefore, no rule as to surplus buoyancy which neglects subdivision by bulkheads can be va'uable, and the ship which is well subdivided according to the Admiralty rule may fairly claim, upon that ground, less freeboard than a ship that is not so subdivided. One of the points to which Mr. Dunn has referred is the great increase of breadth in modern steamers. I am an advocate of an increase of breadth so long as we know exactly what increase of breadth is doing for us and doing against us.

Increase of breadth, if increase of draught of water proportionate to the breadth can be got with it, is an unmitigated benefit; but if that increased draught of water cannot be got in proportion to the breadth, then, my lord, there are certain disadvantages to be faced, and disadvantages which ought to be recognized. Mr. Dunn has referred to the question of the increase of stowage due to beam. There is no doubt that if you only increase the beam of a steamer in a small degree, you may not get capacity accordingly; for in a steamer which is very close pinched for her boiler space you do not get room at the sides of the boiler to stow coal, and thus take full advantage of all your increased capacity; therefore, in increasing beam, the increase should be a bold one, tempered by the consideration of draught. Mr. Dunn has referred to one matter of great importance, and one which, I may say, I have had some influence in introducing to the mercantile marine; that is, the question of structural double bottoms. That idea was started on the East coast; but I believe my firm was the first to make it known, and a practical success. Now with regard to double bottoms, it is perhaps wandering away from the subject to pass a censure on the tonnage committee, but I consider they have gone diametrically opposite to the prudent manner of working which the Admiralty have shown in caring for the safety of the mercantile marine. They have proposed in their report to put a penalty on double bottoms. Any gentleman in this Institution who is acquainted with structural double bottoms knows it is as impossible to stow cargo in them as it is to stow cargo between the floors in an ordinary merchant steamer.

The President. Would it not be well, for the sake of time, as the tonnage measurement comes under discussion to-morrow, if you could make your remarks as short as possible?

Mr. Denny. With pleasure, my lord. I will therefore only speak of the question of double bottoms in so far as safety is concerned. I am happy to see that in one way the diagram Mr. Dunn has brought before us shows a safe double bottom. If you notice, the division of the double bottom is not made in "B" in either the forward hold or after-hold, but abaft it; this indicates that it is a complete double bottom, built without wells for drainage purposes. When we first began building double bottoms we adopted these drainage wells, but Mr. Martell advised us as much as possible to discard them, and although we are occasionally compelled by some owners to put them in, we do not do it of our own free will. A double bottom with wells, however efficiently the valves may be fixed in those wells, is an unsafe thing, because, as everybody acquainted with these valves must know, it is exceedingly likely they will not act when they are wanted to do so, and in that case, in the event of the double bottom being broken open, there is a direct entrance from the sea into the ship. The wells in a double bottom, from being open to the air, are more rapidly oxidized than any other portion of the bottom except that which comes under the boilers, where the corrosion is active and rapid. I would indorse Mr. Dunn's views as to twin screws. I consider it an absurdity that over 10,000 horse-power should be put into one engine. It seems to me when we have got to such excessive power, it should be divided between two engines. I do not agree with Mr. White that a twin screw is the most efficient propeller; but allowing it is not so efficient, and even 5 per cent. less efficient than the single screw, I think the consideration of safety and the consideration of steering, which Mr. Dunn has very properly mentioned, should induce every prudent ship-builder to consider the twin screw favorably.

Mr. MARTELL. I quite agree with Mr. Denny with reference to the praise he has given Mr. Dunn for this paper which has been brought before us. I think, at the same time, it is exceedingly creditable to the Admiralty that, in addition to the amount of work which they must have to do in connection with war ships, they should lay themselves out to afford information to the mercantile marine in the way they have done with regard to this paper. At the same time, as the Institution with which I am connected is supposed to have a great deal to do with merchant ships—seeing that we have something like 1,200,000 tons building under our survey—it would seem to be rather a damaging observation to say that the Admiralty really have a great deal more influence in this matter of safety with regard to this description of ships than an institution such as Lloyd's. I think it should be mentioned, however, in connection with that question, that if Lloyd's Register Society had the power of holding out inducements to the owners of merchant s in the way of employing them, as the Government has, subject to certain things being done which they thought would be beneficial to their safety, they would have a great deal more influence than they have at the present time. The value that has been attached to what the Admiralty has done is, no doubt, greatly due to the inducements which they hold out to the owners of these ships, that if they will do certain things with regard to the safety of the cargo and ships, such as fitting additional bulkheads, &c., they should have a preference with regard to carrying Government goods, when opportunity offers. It is a most excellent thing, and I am very pleased, indeed, to think they have such a power within their hands, and that they can hold out inducements to shipowners to make these additional safeguards. I can only hope they will keep faith with the public in these matters, and after owners have gone to the expense of making these additions as to safety, they will find that the additional expense incurred by them is rewarded by the selection of such ships as these when the opportunity arises for their employment. I think if they go on in that direction they will do a great deal more good than has been done up to the present time, because there is no doubt, unless faith is kept in that way, and that ships, where owners have gone to the great expense of making them additionally safe, will have an advantage when opportunity happens, it is very easy to imagine that they will not be so anxious to continue the improvements going on. There is no doubt the more a ship is divided into bulkheads the safer she is. That is evident. Every one must be confident of that; but though these subdivisions may suit the ships Mr. Denny has referred to, which have to discharge portions of cargo at different ports during a voyage, I can assure Mr. Denny that we have the greatest difficulty in persuading the general ship-building public that it is beneficial to their interest to divide them in this manner. The Committee of Lloyd's Register have recently had this case under their consideration, and the question is still occupying their attention, and there is no doubt the alterations they will make will go on in this direction; but at the same time, with proper regard to the different interests involved and the requirements of trade, they have to be exceedingly careful how they move, and it is not until matters of this kind, which they feel to be essentially necessary for the preservation of ships and for their safety, come before them, that they can be continually requiring alterations of this kind. I am very pleased to be able to say, alterations of this kind, as far as are considered to be really necessary, are going on in this direction. I thoroughly appreciate and recognize the value of them in the safety of ships, and I say I hope not only in the large class of steamers, but in those of smaller size, we shall be able to further divide them in a somewhat similar manner to that shown. I ought not to occupy the attention of the meeting with regard to what has been said about buoyancy, because we shall have enough to say about that to-morrow; but there is only one observation I will make with regard to a remark of Mr. Denny's, and that is, the question of surplus buoyancy is not only that of having sufficient surplus buoyancy after a ship is broken into by collision or other causes, but before the ship is injured in any way it is a matter of great importance to have a sufficient amount of surplus buoyancy to give her a sufficient lifting power to carry her over waves and to prevent her being inundated, and to prevent the waves washing the decks or breaking into the deck openings. Therefore I cannot go the whole way with Mr. Denny in saying surplus buoyancy is no use at all unless you divide a ship out in that way; I think it is of some use. At the same time it would, doubtless, be of more use if you divided a ship further by bulkheads, as suggested in this paper. As I have already said, I do not wish to occupy the attention of the meeting at too great length. It is a most able paper; it gives us a deal of information in connection with the mercantile marine, particularly the large size steamers, and I can only say I am very much obliged to Mr. Dunn, and—I am sure in saying thus I speak for those who are the owners of and interested in the mercantile steam shipping generally—to Mr. Reed, and the Admiralty likewise, because it shows such a vastly improved state of things, when they collect information of this kind in connection with the mercantile marine, to come and place it before the public for the benefit of all concerned.

Mr. W. H. White. I will speak very shortly, and only on four of the points which Mr. Dunn has raised. First, with reference to the use of twin screws in the mercantile marine. I am quite open to conviction there; if it can be proved that twin screws in mercantile ships are not so economical as single screws, nobody would be readier to admit it than I should be. Having had rather exceptional opportunities of examining into the facts, I am distinctly of the contrary opinion, and I believe if the owners of ships of high power embark in twin screws, they will find they have got the advantage of better subdivision, greater precautions against entire disablement, associated with, if anything, a better performance. There may be departures from that view, but I am speaking now of sea-going, deep-draught ships. I am referring not merely to the result of model experiments, but to the result of large-scale experiments, which Mr. Parker knows more about than I do, in some of those twin-screw ships of the "Hill" type which have been recently built, and to which Mr. Denny has alluded. Secondly, as regards the water-tight subdivision, Mr. Dunn has pointed out what is a very important aspect of the question. But he has put so many important matters forward that I think this might be overlooked, therefore I mention it. You may have plenty of bulkheads in a ship, and they may be utterly useless to you. That may arise from too deep loading in relation to the height to which the bulkheads go, or to the want of proper consideration of the frequent necessity for horizontal plating over compartments inclosed by the vertical bulkheads. That is to say, to take any general law, except it has been tested carefully for a particular type of ship, would be dangerous and misleading; and to consider water-tight subdivision independently of the load line is absurd. Then as to improved pumping facilities: I am one of those who look upon pumps as being of comparatively small value as regards the safety of ships—the power of keeping ships afloat when seriously damaged. There can be no question that a good pump is a good thing if it is placed well, and has its source of power placed above the risk of being flooded. All those are very excellent conditions, but for anybody to look to a pump, even were it driven by the whole of the engine power in the ship, to keep a seriously damaged ship afloat, will not bear looking at. The fact is, that a comparatively small hole in the bottom of a ship at moderate depth would drown the whole interior of the ship inevitably, if you had the whole engine power of the ship put on to pump it out. But if you have a ship with numerous water-tight subdivisions, which are always ready for use if the doors and valves are closed, then when the time of accident comes the captain has the assurance of being able to keep the vessel afloat, and is not afraid that the vessel may at any moment sink under him; and the question of clearing the damaged compartment of water is one that can be more deliberately looked at, provided always the pumps are set to work when the inflow has ceased. To set the pumps to work to pump out the sea before the inflow was checked, even if you had 10,000 horse-power, would be a little too hopeful. As to steam-steering gear—and this is the last point I shall refer to—in the ships in the mercantile navy which I have had the opportunity of observing, I have been surprised to find rudders which are not one-half so great as we are commonly accustomed to see in ships of war. I am speaking now of the proportionate dimensions. Now, of course, the designer of a merchant ship has other things to think of than extreme handiness. In war ships that is a very important condition. But supposing nothing else can be touched in a merchant ship, that her form is left unaltered, and her proportions are identical with what they would otherwise be, it is possible to alter the rudder area; and I need scarcely say the question of the acquisition of angular velocity, that is to say, the readiness of the ship to answer her helm, under critical circumstances, varies considerably with the increase of the rudder area. Where there is only manual power, a large rudder area could only be put over slowly to considerable angles, but now we have steam-steering gear so powerful that the largest rudders can be put over and held at the largest angles wanted in something like a quarter of a minute, the conditions are altogether different, and there is no possible objection to the use of large rudders. It does seem to me that a possible source of safety is being thrown away if the rudder area of merchant ships is not made larger in the future than it has been in the past.

Mr. W. Parker. Mr. White having mentioned my name in connection with twin screws *versus* single screws for steamship propulsion, I beg to offer a few observations on that question. Since Mr. White read his very able paper in 1878 on the efficiency of twin screws as compared with single screws fitted in vessels belonging to Her Majesty's navy, I have taken considerable interest in the subject, and for some time past have been collecting data from large steamers in the mercantile marine with a view to comparing, as Mr. White did, the work performed by two vessels of about the same dimensions, power, and draft of water, one fitted with twin screws, the other fitted with a single screw. The most recent additions to the high-powered Atlantic steamers have done so little work up to the present time that it is impossible to determine with any degree of certainty what advantage would have been gained had these vessels been fitted with two propellers instead of one, but as far as my investigations go with smaller vessels—say from 4,500 to 4,000 tons, and an indicated horse power of about 3,000 (I refer to the twin-screw steamers *Scotia*, *Notting Hill*, *Ludgate Hill*, and *Tower Hill*), I feel quite sure in my own mind that these large vessels would have been propelled at very much less cost as regards consumption if they had been fitted with twin screws. The advantages, so far as I can see, to be claimed for twin screws in vessels of exceptionally high power and with a limited draught of water are: First, a more efficient and economical means of propulsion, in consequence of the pitch and surface of each propeller being so proportioned as to give better results than in the case of a single propeller; second, an advantage is to be obtained by dividing large engines (say of 10,000 I. H. P.) into two parts, so far as regards taking to pieces each part, overhauling, and keeping the machinery in good working order. The parts that have to be lifted or moved now in these large engines are of such an enormous weight, and the necessary overhauling takes so much time, that it is very questionable whether these engines can, as vessels are now run, be kept in true working condition; and another important question arises, viz, whether these large parts have not become so heavy and cumbersome that a very great risk is run as to getting them sound. We have a good example of this in the case of the *Servia*, in which case it will be remembered one of her crank shafts, which had been made solid, was found to be so unsound that after the engines had made only a few revolutions it was condemned, and the vessel had to remain at the tail of the bank some six or seven weeks, until another shaft could be made. The third point is safety. There can be little question that a vessel fitted with two screws and two separate engines must be much safer than one fitted with only one large engine, especially if it is admitted that there is a doubt as to the soundness of the parts of the one engine. A vessel capable of steaming 14 knots with two propellers would be perfectly safe, and able to steam from 9 to 10 knots with only one propeller. She would not only be able to keep off a lee shore and be perfectly seaworthy, but would make an ordinary passage. As an illustration of this, I may mention that the twin screw-steamer *Hibernia*, belonging to the Telegraph Maintenance Company, of over 3,000 tons and 1,800 I. H. P., capable of steaming about 12 knots, some years ago was loaded with a cargo of grain at San Francisco for London, and when steaming down to the Cape, her starboard engine unfortunately broke down; the shaft of the broken engine was disconnected, allowing the propeller to revolve, and with the other engine she continued her voyage at the rate of 9 knots per hour until she reached the Equator. By this time the engineers had repaired the broken engine, and the vessel again proceeded at her original speed of 12 knots, but strange to say, when off the Start in the English channel the port engine broke down, and the vessel was again safely steamed with one to London. These are facts which, I think, go to prove that a vessel with twin screws is very much safer than a vessel fitted with a single screw only. The objection to fitting these large steamers with twin screws does not arise from ship-builders or engineers, but from owners, who are advised by their nautical managers (and I think very rightly) that to dock twin vessels, especially in a port like Liverpool, where a strong tide, and very often strong winds prevail, there is great risk of carrying away some of the blades of the propeller, and thus with a ship fully laden and ready to start on her voyage with her complement of passengers, a great deal of inconvenience might occur and great expense be involved. I admit all this, but to my mind it is the wrong way to look at the problem; the vessels would be liable to carry away their propeller blades, because the entrances to the docks are so constructed that the vessel's counters at high water overlap the pier heads, and consequently the propellers would strike the dock wall. But the answer to this objection, in my opinion, is, *alter the dock walls:* the docks were made for the ships, and not the ships for the docks; and I feel sure that if twin screws can be proved to be a more economical means of propelling our large high powered Atlantic steamers than single screws, then the dock and harbor boards must alter their arrangements. There is just one other remark I would like to make, and that is on the subject of pumping power in steamships. Mr. Dunn has referred to it in his paper, and Mr. White has also touched upon it. Mr. White says that a ship could not be saved by pumping power.

Mr. Macfarlane Gray. I quite agree with what has been said by the speakers who preceded me with regard to the merits of the paper, and I will not go again over that ground. I would add to what Mr. Parker has said about pumps, that there ought to be a trial of pumps as well as a speed trial. Sometimes pumps that, according to dimensions, seem all that could be desired, are found to be useless when put to an actual test. Some centrifugal pumps fitted as circulating pumps with alternative connection to the bilges have refused altogether to pump from the bilges when it became necessary so to apply them. Whether the fault is in the engineers or in the pumps, the defect ought to be discovered and rectified by a concerted trial, rather than be left to be found out only when it is too late. The trial could be made when the vessel is in water of a depth only a few feet in excess of her draught, so that if the pumps failed the vessel would ground only, not sink. The paper we have heard satisfactorily reports on the development of steam navigation and the acquirement by steamships of, as it were, new organs, and I am led by that review naturally to think out what may be still wanting. The power of signaling by sound the compass course a vessel is on to neighboring vessels in fog and thick weather is, I think, now one of the most pressing wants. The rapidly increasing crowding of steamers on some ocean tracks, and the increasing speeds, ought to be accompanied by some such provisions for the prevention of collisions, since it is admitted by every one that vessels cannot be constructed to withstand collisions. In the next report of progress I hope that this want will have been supplied.

Mr. A. C. Kirk. My lord, I will only detain you by a very few remarks. The subject of twin screws has been practically exhausted. Much has been said about the difficulty of docking, but nobody has said anything about the increased facility of docking the twin screw affords. In Liverpool, with a single screw you have to be pulled by hawsers round the corner against the entrance wall, and there is very great difficulty, whereas with a twin screw, although a ship has no way on her, you can, so to speak, steer her. In going down the Clyde in one of Her Majesty's steamers—just to give an instance of what has been done with a twin screw—the steering gear practically became quite useless at an early stage of the journey. She had no steam starting gear, but by getting down a good gang of riggers to the starting wheels that ship was safely steered down the Clyde to the tail of the bend purely by the two main engines alone. Further than that I will not say anything on the subject of twin screws. I think as to the matter of pumping power, Mr. Parker and Mr. White are both right. They have looked at it from two somewhat different points of view. Mr. Parker is perfectly right; if water gets into a stokehole, even in large quantities from above, then the fire may be put out and the whole ship become unmanageable; but good pumps will master that condition of things perfectly well. Mr. Macfarlane Gray suggested a test of pumps, but a test of pumps, to be of any use in that case, would require to be a test addressed to a set of pumps pumping about half coals and half water, or, as I have known, even a whole lot of tallow candles which had got adrift. As an illustration of what pumps can do I would quote the case of one of the Pacific Company's steamers—I cannot name her at this moment—which was lost at Maldonado, in which, by the use of the ordinary circulating pumps at tached to the engines, she was kept moving gradually slower and slower, although the boilers were drowned out completely and the water was up to very nearly the bottom of the steam cylinders, the water was kept down sufficiently till the captain was able to run her ashore.

Mr. Ravenhill. Having had the honor some years ago of bringing under the notice of the institution, I believe for the first time, the great strides which had then been made in the speed of some of the passenger steamers across the Atlantic, I venture to trouble you this afternoon for a few minutes. Since that date no doubt very, very great progress has been made. You may remember that I alluded to the arrival of the *Lusitania*, of the Orient line, out at Melbourne in the paper I then read to you. Since that time a vessel called the *Orient* has been built, and she has run about 45,000 miles at a speed of 13.55 knots per hour. We have heard to-day of the *Stirling Castle*. I may tell you that her speed at the mile the other day was 18½ knots, with 100 lbs. of steam. Now, if that vessel attains the speed that those who are connected with her hope and anticipate, she is to bring home her cargo of tea at something like 16 knots an hour. And perhaps the best way I can demonstrate that increase of speed to you is this, that working out the relative speed of the *Orient* between Plymouth and Adelaide and the *Stirling Castle* if placed on the same station, it would make a difference of five days in the length of passage, the one occupying 32.75 days and the other 27.7 days. That is an enormous stride. There is one point, also, in connection with these new vessels that they are building on the Clyde which has not been alluded to, and where the engineers and owners are now following the practice which has been adopted in the Admiralty for a great number of years. Our commercial marine adhered to the cast-iron propeller long after the Admiralty were using gun-metal propellers in every iron vessel that they had built. I am told—in fact, I have seen them there lately—they are using propellers on the Clyde made with steel bosses and propeller blades of phosphor bronze, and they find considerable advantage by following that system, and they attribute a portion of the higher results they are obtaining from the lesser friction caused by the use of the phosphor bronze blades as they revolve in the water over that of cast iron propeller blades. With reference to what has been mentioned by the writer of the paper, and he has drawn our attention in No. 6 to greater beam, I may mention that the *Stirling Castle's* beam in proportion to the length is something under 9 to 1. She carries coal, or is to carry coal, for twenty-four days' steaming, and I hope next year the results will be placed before the Institution. One word about twin screws and the advantages *pro* and *con* as compared with the single screw. It has been discussed oftentimes in this Institution, and from my own experience many years ago there was no doubt about it, we did get a better result with twin screws than we did with a single screw. You have greater increased safety, as has been mentioned by previous speakers here this afternoon, when you are using twin screws as compared with single ones; you have also this greater advantage, that you can subdivide your vessel by the fore and aft bulkheads in the way our navy vessels are now fitted if the twin-screw system is adopted in our large ocean-going steamers.

Mr. Reynolds. I wish only to ask one question. The remarks that have been made in praise of twin screws may be taken as truisms, but I should like to know whether our merchant ships fitted with twin screws have displayed any of the eccentricities of steering that some of our iron-clads have done. The last trial of the *Inflexible* showed that she required to carry her helm 18½ degrees sometimes one way and sometimes another, and vessels since launched have been fitted with enormous rudders. Then, in correction of Mr. Parker, I may say that one at least of those ships has in one of her passages damaged both of her screws. The blades were bent, showing possibly that there may have been a little of that eccentricity of steering, and showing also practically they are a little more liable to damage than single screws.

Mr. John. As the matter has been practically exhausted, I will only refer to one point in Mr. Dunn's paper, and that is the question of bulkheads. The question of bulkheads comes up periodically, and is ventilated here. There are difficulties about the question of bulkheads which I should like to point out, and which I have always felt from many years' connection with Lloyd's, and I am afraid there will always be the same difficulties. In the first place, I should like to say that as far as passenger ships are concerned, where it is a question of human life, I fully indorse all that has been said about ships being so subdivided that they will not sink if one compartment is flooded. That should be carried out and enforced by the Government of this country, and should not be left to shipowners or Lloyd's or any other body. When it comes to a question of property, the whole matter is changed entirely, as I will show you. You take a sailing ship; you take the iron sailing ships of this day up to 1,500 or 2,000 tons. They have only a single collision bulkhead in the bow, and if Lloyd's were to attempt to enforce a subdivision of those sailing ships they would be met with such an outcry from the owners of those ships that they could not maintain their position for a day. What is more, they would so cripple the taxation of those ships, and for so small a gain, that they could not maintain it Because those ships are amongst the safest ships in the country, they are the ships the underwriters pay the least premium upon, and Lloyd's could not interfere with them. Now, when it comes to cargo steamers, Lloyd's naturally recognize that at the stern there are the dangers in connection with the propeller shaft, and they have a bulkhead there; in addition, they have also bulkheads at the ends of the engine-room, the machinery compartments. They are necessary bulkheads; but when it comes to forming a further subdivision they would be met in this way: Our owner says, No. In some trades it is valueless, in others it is a necessity of the trade, and they do it as a matter of course for the purpose pointed out by Mr. Denny, of calling from port to port; but where it suits an owner's trade to have a large hold, a fore hold and a large after hold, for Lloyd's or anybody to say, No, you must have her bulkheads to divide the ship like those two bulkheads B, I ask, what is the position of Lloyd's if the owner says, No? Here I cannot only dispense with those two bulkheads B, but I can take out those three bulkheads A, and turn the ship into a safe sailing ship. And unless you are able to enforce that principle through the whole of the weight-carrying ships, sailing ships as well as steamers, you cannot adopt the principle that an iron ship must be so subdivided that one compartment can be flooded without the ship going down. Therefore, I say, we must recognize that feature of the thing as one of the salient points. There is only one other point I would mention; it is about the double bottom Mr. Denny mentioned. No wells are shown there, but I think Lloyd's require a well at the end of each compartment, and that is another case where, to prevent or to minimize damage to cargo, some sacrifice of safety takes place. And you cannot help it, because you may dispense with the double bottom altogether, and the double bottom, as it is now in the mercantile marine, would never have been introduced for the purpose merely of safety, but for other considerations, economical considerations, and therefore you have it for the purposes of trade. I wish to dwell upon the point that double bottoms in the merchant service are not for the purpose of safety, although they contribute in that direction, and they would never have been introduced if it had not been for economical and commercial reasons.

Mr. W. Rundell. My lord, I would not introduce any observations.

at this stage of the discussion if I did not think I had something interesting to say upon it. I offer this as an apology for speaking on a subject which has been somewhat exhausted. Like Mr. John, my intention is to speak to one point only, that relating to bulkheads. I have had a good deal of experience on this subject, and my experience may to some extent throw light on this subject of encouraging the use of bulkheads. I allude to an experiment which was tried by the registry, with which I am connected, more than twenty years ago. They did offer a premium for the introduction of a sufficient number of bulkheads to insure a moderate degree of safety against the effect of collisions at sea. The mode they adopted was this, to offer a better class in the register book, whereby owners could effect their insurances on better terms; not only was the registry committee desirous of improving the safety of the vessel by increasing the number of bulkheads, but the underwriters combined with them by offering lower premiums. The basis of the arrangement was this: as Mr. White pointed out, there must be a relation between the number of bulkheads or the spaces occupied between them, and the spare buoyancy of the ship. The spare buoyancy being assumed at 30 per cent., it was thought that if no part of the vessel separated by bulkheads exceeded 20 per cent. of the total displacement, under ordinary circumstances the ship would be safe, because there would be a good margin beyond—there would be the margin of 10 per cent. Now, a gentleman who was very ardent in this matter built a sailing ship to suit this arrangement, and she was specially designed to have these five bulkheads. He, however, did it once only; he built other ships, but he did not build a second ship in this way. He found it an incumbrance in very many important respects; it cost him a good deal to begin with, and there was the interest of the money; he found he could not earn the freights he might have earned if the bulkheads had not been there; that the ship was only adapted to certain cargoes, and that it involved great loss. Now the case is rather different with regard to steamers, because steamers have usually an increased number of bulkheads. It is not unusual for a steamer to have seven, eight, or nine bulkheads; at all events, more than five, the limiting number. Here the difficulty did not lie in the number of bulkheads, but in the spacing of them, because the rule was that they should be so spaced as not to inclose more than 20 per cent. of the total bulk of the vessel. If they inclosed more than that they were useless for the purpose of classification. Some score of steamers were built to obtain the proposed class, but the special class soon fell out of use. Now, taking another point of view: supposing a vessel had a number of bulkheads, and that no division occupied more than 20 per cent. of the total bulk, the underwriters would look upon her as safe in regard to ordinary casualties. But if a collision happened, and two compartments were flooded, the additional number of bulkheads would be of no service. But I may point out the case is considerably altered now by the double bottom arrangement: that conduces quite as much to the safety of the vessel as the division by bulkheads, perhaps more, and I am not quite sure but that the Admiralty, if they again looked at the matter, might be induced to give some encouragement to vessels with double bottoms. But perhaps from the Admiralty point of view the bottom is not likely to suffer from the effect of a shot hole. As to a shot hole in the side of an iron vessel, one cannot say what size it might be; it would depend very much upon the quality of the iron. I think we cannot limit the size, and, as Mr. White pointed out, pumping arrangements would have to be very extraordinary that would meet that case; but in a steel vessel the shot hole would be very limited in size, and the pumps would perhaps be able to manage it. We have heard of double-bottom vessels with rents in them that would let a horse and cart through, yet they have been quite safe and able to get into port. I know of one case where a vessel with a serious rent was going to sea again without knowing there was any injury in the double bottom, but they were pumping—they wanted to clear the tank—and they found it was not possible to do it. They were pumping the sea up; the rent was so big that there was no possibility of clearing it. That vessel, when she went into dock, was found so damaged that if it had not been for the double bottom she must inevitably have sunk. Now, in some cases where the rent has been large—I speak from experience—so large that it would be impossible to save the vessel by pumping alone, a sail has been put over it quickly, and the rush of the water into the hole draws the sail in so rapidly that it quickly brings the pumping power into such efficient use that it saves the vessel. This paper suggests a number of interesting topics, and there are many points I could dwell upon, but as my lord has pointed to the clock, I will cease at once, and end with the question of bulkheads.

Mr. Dunn. I have only to express the gratification I feel that my paper has led to so full, interesting, and valuable a discussion.

The President. I am sure I may convey to Mr. Dunn our united thanks for his very valuable paper, and also to those who have contributed to the discussion.

BULKHEADS.

By James Dunn, Esq., Member.

[Read at the twenty-fourth session of the Institution of Naval Architects, 14th March 1883; president in the chair.]

In a treatment of the subject of bulkheads, I do not propose to deal with our men of war, because it is well known that the Admiralty has accepted the principle that for war purposes a ship should be subdivided into as large a number of water-tight compartments as is practicable; and to such an extent is this carried that in some of our armor-clads may be found upwards of one hundred separate and distinct spaces, a considerable number of which may be destroyed by the penetration of projectiles or by collision without the floating powers of the ship being seriously impaired.

I propose rather to deal with vessels of the mercantile marine, in which, besides being our chief source of commercial enterprise and wealth, the state itself is so largely and increasingly interested; and for this purpose I will submit three propositions for consideration:

I. Is the subdivision of a merchant ship by water-tight bulkheads practicable and consistent with commercial requirements?

II. Can these bulkheads be made sufficiently strong to withstand the pressure of water under all circumstances?

III. Are bulkheads of any value in securing floating powers for the ship in the event of damage from collision or other causes?

It may be thought that the order of these propositions might have been reversed, but the reason for placing them as I have done will become apparent.

I. In considering whether they are practicable and consistent with commercial success, I would prefer to give facts rather than opinions; but I may be permitted to say here that it has been my duty for several years to give special attention to this question for merchant ships, and I have had the opportunity and advantage of fairly considering it in its wide and several bearings in consultation with the shipowners.

In our early days of iron ships we found them with a collision bulkhead placed at a few feet from the bow, and of great value it has proved.

At the stern also was a bulkhead, or a box, through which the shaft passed water-tight into the tunnel or passage; and inclosing the machinery and coal space, or money-spending department, were two iron bulkheads required by act of Parliament, thus leaving two spaces, the fore and after holds, for the freight-carrying or money-earning branch.

At that time such an arrangement practically divided the ship into three equal lengths, which was thought very satisfactory. By and by shipowners' views expanded; they lengthened their ships, but reduced the machinery space by means of improved machinery, so that the cargo holds became each more than twice the length of the midship compartment. Then, *i. e.*, in 1862, that section of the merchant shipping act was repealed which gave to the board of trade surveyors the power to require water tight partitions to be fitted.

We cannot believe that this repeal was intended to encourage the idea that water-tight partitions were unnecessary, but rather that in large vessels more partitions than the provisions of the act required were necessary to secure the safety of the ship, and it was doubtless thought better to leave builders and designers unfettered than to tie them down by general statutory regulations. Otherwise the state, in case of loss, might have been credited with the blame, on account of the deficient bulkhead arrangements authorized.

The spirit in which this view was accepted is indicated in the substance of this paper.

The partitioning off of the machinery space was, however, a necessity, and was continued, and in this position the Admiralty found the question, when, in 1875, the subject was investigated. They laid it down as an axiom, or rather reaffirmed it, that no ship should be considered suitable for purposes of the State without her bulkheads being so arranged that if any one of her compartments were laid open to the sea in smooth water the loss of buoyancy thereby occasioned should not endanger the safety of the ship; and after careful inquiry, the serious conclusion arrived at was, that there were not thirty British ocean-going ships in existence complying with this requirement, securing a minimum measure of safety.

The attention of the shipowners was then invited to the subject, and nobly have they responded, for at the present moment there are 300 such ships, including all the latest built first-class steamers, and many in the several other classes; and there are some now building which embody the all-important and additional advantage that they will be able to dispense with the buoyancy of *any two* compartments, and still retain sufficient floating power. While congratulating ourselves on having as many as 300 well-divided ships, we must not forget that there are more than 4,000 ships of 100 tons and upwards which would sink if any compartment between the collision and stuffing-box bulkheads were laid open to the sea in smooth water.

It is worthy of notice that the gentlemen forming the committee and staff of Lloyd's registry have by their action shown their view of the importance of this question.

In 1880 they *recommended* for ships 280 feet long and upwards that a divisional bulkhead should be fitted in the forehold, extending to the main deck.

In December, 1881, the recommendation is omitted, and the fitting made compulsory.

In June, 1882, the divisional bulkhead in main hold is to be carried to the main or upper deck, and a corresponding bulkhead is to be fitted in the after hold in all ships 330 feet in length and upwards.

And they went further still, and required that in their one, two, and three-decked ships the bulkheads inclosing the machinery space should be carried water-tight to the upper deck.

This welcome progress we hope will go on, and that we shall some day learn that "spar deck" and "awning deck" steamers are to be similarly well treated.

And we shall hope, too, that the divisional bulkheads shall be fitted in all classes, and that they shall not, as they may now, stop at the deck which is awash, but that they shall be carried to a deck well above the load water line.

One important fact I will name before leaving this branch of the subject, and that is that in no instance where an owner has introduced the additional bulkheads asked for by the Admiralty has he retreated, but rather has he advanced. And this, I submit, is an answer to be accepted to the proposition that bulkheads are practicable and consistent with commercial success.

II. We have now to consider as a second proposition whether bulkheads can reasonably, and with moderate weight of material, be made to withstand the extreme forces to which they may be exposed.

What are these forces?

To consider the question fairly, we will assume one compartment laid open to the sea by the tearing of the side plating, and we shall have—

(1.) The statical pressure due to the given depth of the water in the hold when the ship is at rest and no cargo on board.

(2.) That due to the pressure when the holds are wholly or partially filled with cargo and the ship still at rest.

(3.) That due to the extra pressure when the ship is under way, or alternately rising on the crest or falling to the hollow of a wave.

(4.) That due to the rolling, pitching, and 'scending of the ship herself.

The first condition can readily at any time be tested, either by filling a compartment when a ship is on the blocks, and the test water can readily be cleared, or it may be done afloat, when the pumping powers may be tested in the clearance of the water.

It will, perhaps, be said that this is not a test, that there are times when a much more severe strain is brought to bear, when the side is torn open, and the full force of the sea has to be met, or when the water is rushing to and fro, caused by the motion of the ship itself. I would submit that a parallel to even this test may be applied by providing a pipe with a head of water of, say, four or five feet above the water level, for I do not think that under any circumstances will the bulkhead be more severely tried.

When the hold is partly occupied by cargo the volume of water is limited, its depth is lessened, and its movement is retarded.

In the case of the traveling ship, or the traveling wave, with its hollow and crest alternately rushing along the ruptured side, one might at first sight expect a great variation in the depth of water inside the ship, and a corresponding increased or lessened pressure, but it will be found in reality that the motion of the water outside does not indicate what is going on inside, as, through the largest cavity of which we have any knowledge, the water has not time to get in and out again with the speed of the passing wave, and the difference in the pressure on the bulkhead is consequently only that due to a not important variation in the depth, or it is a statical rather than a dynamical force. Where the hold is occupied by cargo we have already said the motion of the water is stayed, and in spaces where the water is free, the motion of the ship having a varying period from the surrounding waves, the movement of the water is dilatory, and the pressure on the bulkhead varies very little and very slowly.

Much, of course, depends upon the position of the hole and the state of the weather. If at the broadside and the water is smooth, the pressure is known. If in a seaway, the water runs past the hole, and little variation in pressure occurs. But if the hole is in the bows the tendency is for the water to get heaped up in proportion to the speed at which the ship is traveling. Some interesting results illustrating this were obtained some time ago at the Admiralty experiment work at Torquay.

With the pitching and 'scending ship, extra forces are thrust on the bulkheads at the ends of the ship, and point to the necessity of making the end bulkheads, and especially the collision bulkhead, exceptionally strong; and it becomes the duty of the naval architect to consider the fact and prepare to meet it. How is this generally attempted? The very general practice is to adopt the rules laid down by Lloyd's registry, which provide for plating four-sixteenths of an inch in thickness for a 1,000 ton ship, to seven-sixteenths of an inch in thickness for the largest class. In the smaller ship the plating is stiffened with vertical angle bars, with flanges of 3 inches and 2½ inches in width and five-sixteenths of an inch in thickness, placed 30 inches apart. And for the largest type of ship, with the thicker plating, these vertical stiffening bars are still placed 30 inches apart, but the flanges are each 4½ inches wide, and their thickness is increased to seven-sixteenths of an inch.

Where a deck exists, it of course acts as a longitudinal stiffener or prop; and where the internal arrangements dispense with a deck, but where the distance between the horizontal angle bar at the head of the bulkhead and the floor exceeds 8 feet, an angle bar equal to the main frame of the ship is riveted to the bulkhead on the opposite side to that on which the vertical stiffeners are placed, and arranged horizontally; and where this distance exceeds 12 feet two such stiffeners are provided, and so on, the number of them being added to as the depth increases.

These arrangements, I submit, if efficiently carried out, should be sufficient to enable the bulkheads to hold their own in ships of the narrower type; and, as a fact, we know they have actually withstood the test under severe trials.

I may be asked to cite cases; some will be given later on in this paper, and the details of some others will be found in the paper which I had the honor of reading before this Institution last year.

We know, too, of many cases where the bulkheads have given way, but an examination would doubtless have disclosed neglect of the precautions to which I have referred; for too often have we found both horizontal and vertical stiffener cut for some insignificant purpose; the main prop of the bulkhead has been cast loose, and no wonder that in the hour of trial they have been found wanting, and the loss of the ship has been the consequence. While asserting the opinion that the rules referred to are in general sufficient to meet the case, we must remember that our merchant ships are increasing in breadth.

Three years ago 50 feet was a great beam; we have now an Atlantic liner with a beam of 57 feet; and the time has come for us to consider what additional means must be adopted to secure the safety of bulkheads. I would urge now for ships of great breadth, and for bulkheads of great area, that a vertical web-plate should be fitted at the middle line, say from 12 to 24 inches in depth, with angle bar flanges, and secured to the bulkhead and to the several decks and the floors; and I shall hope to see some of the angle bars between it and the sides of the ship replaced by good stiff bars of a Z section. I think we need not then fear to receive a good account of the ship when tested in this particular way.

Given, as I have before said, a bulkhead structurally arranged as described, well calked and made water-tight to start with—a duty too often neglected—we have no fear but that it will be sufficiently strong to withstand the pressure of water to which, under the most extreme circumstances, it may be subjected.

III. I shall ask you to agree with me that a more general introduction of bulkheads is practicable, and that they can be made of sufficient strength, and I will now ask you to consider with me whether they are likely to be of any value for flotation purposes in the event of a ship having her bottom injured from collision or other causes.

We contend that they are useless if not wisely placed, nor carried high enough, nor efficiently cared for; they are useless when found, as we have found them, with stiffeners cut, with rivets omitted, with calking neglected, with plates removed, with large holes cut for small pipes to pass through, with sluice holes and no covers, with doors and worthless securities, or with open doors rusted and unmanageable, or with doors in the holds fastened open in such a way that they cannot be closed without "handling," and are out of reach at the moment of danger.

We will go further and say that they are not only useless, but that under some circumstances they are positively dangerous. This may, perhaps, be thought a serious and startling assertion; but we will take the case of a ship illustrated by Fig. 1, Plate I—and there are many such ships now afloat—in which a good number, a really large number, of bulkheads are provided and distributed as shown, but three of which, it will be seen, are stopped at the deck which is awash. The bottom gets damaged and springs a leak, say in No. 1 hold, or in No. 2 hold, or in both; and how many such cases have we known where the water enters and gains on the pumps, and slowly, but surely, rises to the top of the dwarf bulkhead, causing the ship to trim, as indicated in Fig. 2, Plate I.

The water is then free to flow over the top of the bulkhead and pour into the next hold, the effect of which is inevitably to send her head-first to the bottom.

Now we assert that such a ship would keep afloat with the water in No. 1 hold *and* in No. 2 hold, provided it is confined by the bounding bulkheads being carried a few feet higher than the natural level. What this natural level is, and to what height the bulkhead should be carried, are points readily determined by the naval architect.

But if they are not carried up, but are left as shown—and in too many cases they are so left—then we say they had better not be in the ship at all, as they will contribute to her loss by keeping the water at one end of the ship and carrying her bows under; whereas, if they are not fitted, the same volume of water entering as is indicated in the preceding diagram, and not being confined to one end, will distribute itself through the ship all fore and aft, in which case the trim is preserved, and she will still float in the position indicated in Fig. 3, Plate I.

Here although the freeboard is reduced, she will still be seaworthy; the fires may be kept burning and the machinery going sufficiently long to bridge over the space dividing life from untimely death.

We will now take another view, and consider two cases, in one of which the bulkheads were well placed and cared for, and proved that under such conditions they may be of the greatest value; the other case is in all respects a contrast. In the first case they were placed in the positions and carried to the height indicated in Fig. 4, Plate I.

A steamer of nearly 5,000 tons ran into this ship in a fog, struck her abreast of No. 3 bulkhead, opening up two compartments to the sea: but, fortunately, the bulkheads had been carried to a reasonable height, and the water could not get beyond them; they stood the test; she did not sink, but she kept afloat at the trim shown in Fig. 5, and in this condition steamed 300 miles safely into port.

Happily, we are now getting a number of such ships, and many similar facts giving actual beneficial results might be placed before you if time would permit, so we will consider the next case, where we have the same number and a similar disposition of bulkheads as in the previous case; but, unfortunately, some of them are rendered valueless by being stopped at or about the water line, as indicated in Fig. 6, Plate I.

This sketch represents a large number of first-class steamers now afloat, and should such an accident happen to any of them as has just been described, they would certainly not have the good fortune to complete their journey, as in our last case; but the water, not being confined to the two holds numbered 2 and 3, as it was in the previous case—which is an actual one—will pour over the top of the dwarf bulkhead into the formost hold; and the ship will soon get into the position indicated in Fig. 7, Plate I.

Water will then be reported to be making in the engine-room, if indeed she should not disappear before then.

By desire of Mr. Barnaby, one of our vice-presidents, and with the sanction of the Admiralty, two fair sized models have been made to represent the merchant steamer of a very acceptable type, judging from the large number built and building.

In one of these models are placed the bulkheads according to a common practice, *i. e.*, with the two bulkheads inclosing the machinery space and a divisional bulkhead in the fore hold.

In the other the bulkheads are arranged so as to represent a ship entitled to admission to what is known as the "admiralty list," *i. e.*, with four bulkheads beside those at the bow and stern viz, two inclosing the machinery space, one divisional bulkhead in the fore hold, and a corresponding one in the after hold, all of which are carried to the upper deck.

Figs. B and G, Plate I will enable you to form an idea of the kind of ships (about 3,500 tons gross register) represented by the models.

I regret that it has not been convenient to bring the models and tank here, but I have permission to say that any member of this Institution may see them and operate with them at the Admiralty office, 28 Spring Gardens. You might then judge for yourselves as to the advantages of good water-tight subdivision.

We have shown how bulkheads, when ignorantly treated, may be useless and even dangerous, but we maintain that when wisely dealt with they are of the utmost value, both from humane and economic considerations.

The models are loaded with weighted wood blocks, the blocks being of a bulk to represent the cargo in a passenger ship floating at an ordinary load draft with each compartment below the upper 'tween decks appropriated to cargo, having one-half its space occupied—a condition ordinarily assumed at the Admiralty when determining whether a ship is qualified for the Admiralty list—and they fairly represent such a ship as regards their measure of stability.

A hole is made through the bottom plating, to represent an actual hole, about one square foot in area and eight feet below the water surface in each compartment, and a plug is placed in it, so that by removing a plug any part of the model may be laid open to the water.

The first, which we will call B, or the badly bulkheaded model, very soon disappears after the withdrawal of any one of the plugs, because the water rushing in soon rises to the level of the water outside, and is then, or before then, free to flow over the top of the dwarf bulkhead into the adjoining hold.

Take, for example, the plug out of the bottom in way of No. 1 hold.

But if the corresponding hole in the good, or G model is opened up, the water soon gets in and finds its level, but it is then confined between the bulkheads, and the model remains afloat in the position indicated in sketch G_1, Plate I.

Whatever experiment is made in this direction with the B model, the result is the same, viz, she goes down; so we will dismiss her from further consideration, and go back to the G model.

We have already shown her in position with the forward compartment filled in sketch G_1, and that sketch also represents the trim she would take if the damage were to occur in the second hold from forward instead of the first, because, although this No. 2 hold may be and often is the larger, it is nearer the center of gravity of the water plane, the leverage is less, and the effect on the trim is modified.

Take another case, and open up both the forward holds, Nos. 1 and 2. Of course we expect that the ship will then go down, because the alteration of trim will be so great that the top of the boiler-room bulkhead, although carried to the upper deck, is dragged below water, and the engine-room becomes filled; and thus we have the forward *three* compartments full, which would undoubtedly sink her.

But suppose we keep the water out of the engine-room, which we can do by making water-tight the casing round the funnel and engine-room hatch to, say, eight feet above the deck. I will not affirm that this is practicable, nor will I ask you to do it, but it may be of interest to know that in smooth water the ship would have buoyancy and stability, even when in this damaged state, and would float, as indicated in sketch G_{11}, Plate I.

Other cases of interest might be produced if the rules of this Institution with regard to time were transgressed, but I do not now propose being a transgressor, so will ask you to accept my statement that the ship would behave in a similar way if the after compartments were laid open to the sea; that the ship would float with the buoyancy of the machinery compartment lost; and that she would also keep afloat with *two* of her cargo holds damaged, provided one is forward and the other aft. The freeboard certainly would be small, but under ordinary circumstances she would keep afloat in smooth water and have stability. And we must remember how many collisions occur in a fog, when the water is smooth; more, indeed, than happen in a heavy sea.

I do not propose, at this time and in this paper, to deal with the question of transverse stability in these particular circumstances, further than to state that in these models some attention has been paid to give them a measure of stability comparable with that possessed by a merchant ship carrying cargo in her holds and passengers in her 'tween decks, and that they keep upright and possess stability when partially and when wholly immersed.

I mention this fact here because it will perhaps be noticed that I have dealt with the transverse bulkhead question only, and have not advised fore and aft middle-line bulkheads, as they, by keeping the water on one side, will sooner bring the perhaps unsecured side-lights under water, may give the ship an unsafe heel, and accelerate her destruction. There really is no choice when we can secure a moderate change of trim by means of good transverse subdivision, or have the same change of trim and a considerable loss of stability produced by longitudinal bulkheads at twice the expense and weight in material, besides the inconvenience of stowing machinery and the like in the holds. There are, moreover, objections to the middle line bulkhead on grounds of strength when placed at the ends of the ship ; rather would I see it through the midship part, where the weights are heavy, and where then the maximum strains might receive their equivalent in strength.

This bulkhead question has so many phases that one is continually tempted to amplify, but I have endeavored to look at the question from the point of view in which bulkheads give floating powers to a ship. That this is of importance must be admitted without the necessity of being reminded that in each of the two past years more than fifty steamers have sunk through collisions alone. And a consideration of the subject by this Institution will hasten on the claims of water-tight subdivision, and lead to the time when we shall not be satisfied to ask that the ship shall be safe with one compartment in communication with the sea, but that she shall be safe when struck on a bulkhead, throwing open two compartments.

As an illustration of the great general importance of the subject of bulkheads in merchant steamers, the following statistical details and deductions should be of interest. The advantages of good subdivision are broadly indicated in the annexed table:

	Average number in existence during six years ended December, 1882.	Average annual loss from all causes during six years ended December, 1882.	Average loss per annum.
Ships qualified for the Admiralty list	157	$1\frac{5}{6}$	1 in 86
Ships not qualified for the Admiralty list	3,483	136	1 in 25

These figures are very significant. It appears from them that the chances of loss from any cause are nearly four times as great for a ship not constructed to qualify for the admiralty list as for a ship entered on that list. This proportion is greatly due to the almost absolute immunity from loss by collision of ships on the list, for during the first four and a half years of its existence not one ship was lost from it by collision, although a considerable number of the qualified ships had been in collision, and escaped foundering on account of the safety afforded by their bulkheads. Within the last year, however, we have had six casualties to ships on the list, and among them was our only loss by collision. In that case, the whole of the ship—a small one—was flooded abaft the engine-room, the two after holds being opened to the sea. This was a case such as we have no merchant steamers afloat capable of surviving.

The smallness of the loss from the Admiralty list may also be due, to some extent, to the ships thereon belonging to wealthier companies, being better found and manned, and being more employed on ocean routes, besides that they may less often carry dangerous cargoes, or be overloaded, than the smaller ships.

None of these circumstances greatly affect the fate of a ship after collision, nor do they, as we shall show, reduce the *a priori* risk of collision; but they supply almost certainly the reason why no ships have in the last six years been lost from the list by foundering or by fire.

During this time, the whole of the losses from the Admiralty list (11 in number) have been from drifting on rocks, or otherwise getting fixed on shore, with the solitary exception above quoted.

In the same period, 76 ships have been lost which had been offered for admission to the Admiralty list, but had not been found qualified; of these, 17, or 22½ per cent., were lost by collision, and 10, or 13¼ per cent., were lost by foundering; most of the rest stranded or broke up on rocks.

That the general superior character of the ships on the list is of no value in reducing the risk of collision is shown by the following comparison.

We can prove that of the entire British mercantile fleet of steamers, about 1 per cent., without distinction, receive damage of a fatal character by collision during the year.

Of the number thus damaged, those on the list remain afloat, while those not on the list are lost.

This is deduced from the following figures: Referring to the table given above we will only take those cases of collision of ships on the list which would have proved fatal but for their compliance with Admiralty requirements. These are 9, or an average of 1½ per year, giving 1½ in 157, or 1 *per cent. of prevented fatal cases.*

Again, the average number of ships sunk by collision per year from the unqualified part of the fleet is 35, and the average annual record of the fleet for the six years is about 3,500, also giving 1 *per cent. of* (in this case) *fatal cases.*

Thus our statement is substantiated, that the risk of *fatal* collision is about 1 to 100, irrespective of the class of ship, and that ships on the Admiralty list enjoy almost absolute immunity from loss by this cause.

It is, therefore, proper to consider that the vessels on the list have no natural advantage with regard to their safety beyond that due to their bulkheads. Our object is to show that this simple advantage is of immense value, and the rational deduction from the above considerations would seem to be that, having regard to commercial and monetary interests, as well as to the preservation of life and property, a ship should be subdivided by as many transverse bulkheads as practicable, all carried high enough to be efficient in securing the good results above exemplified.

SPEED AND CARRYING OF SCREW-STEAMERS.

[Delivered before Greenock, Scotland, Philosophical Society.]

Before beginning my lecture, I desire to thank your Institution and your committee for having done me the honor of asking me to deliver the Watt lecture for this year. Our gratitude to that great and skillful engineer well deserves to be kept fresh by annual commemoration, and I only regret that, as a ship-builder, it is not in my power to do his memory the fullest honor, by speaking on the vast changes his genius produced, and under new forms still continues to produce, in the marine engine. I am not a marine engineer, and do not propose in this lecture entering further into that domain than to point out the relationship between the power of the marine engine and the hull it has to propel, and to touch upon conditions regulating its advantageous employment in screw-steamers of different types. As, however, this relationship between the hull and machinery is vital to the whole question of ocean steam navigation and its future, forming the foundation of all speculation and hope regarding it, I trust that, although my treatment of it may fall short of what you have a right to expect in a lecture devoted to the memory of the greatest of marine engineers, it will at least form some stimulus and incitement to a further and bolder study of the subject.

By the speed and carrying of screw-steamers I mean the speed at sea and the dead-weight carrying capacity of these vessels. The measurement capacity is a subject large enough for a lecture in itself, and so closely related to the tonnage question, that it would be impossible to treat of it apart. The importance of speed and dead-weight capacity is sufficiently vouched for, on the one hand, by the great interest at present centered in the wonderful speeds attained by the best torpedo-boats, and on the other hand by the practice, so prevalent in the case of cargo-carrying steamers, of rating their cost upon their dead-weight capacity. I purpose treating these two subjects in three successive ways; *first*, by attempting to lay before you in as concise a manner as possible the general principles underlying them; *secondly*, by placing before you some demonstration of these principles from known and practical results of screw-steamers at present afloat; and, *thirdly*, by gathering from these two methods of treatment some hints and suggestions as to the possibilities of the future.

Before proceeding further, it is desirable that you should obtain a firm grasp of the meaning attached by naval architects to the word displacement. In its simplest form it means the amount of water displaced by any body floating in water. You know that such displacement must occur if we place an egg in a tumbler of salt and water of sufficient density to float it, and if before placing it in the tumbler the tumbler were full to the edge, then the egg would displace from the tumbler a certain amount of water which would flow over. Were we to collect carefully the water which overflowed to enable the egg to float, and to weigh that quantity of water, we would find out that its weight was exactly equal to the weight of the floating egg. This is the scientific fact from which all calculations in naval architecture take their rise, that any ship afloat displaces its own weight of the water it floats in. If, therefore, we can either weigh or estimate by measurement the amount of water displaced by the ship, we shall, know its exact weight. As I am very anxious that you should have proof of this fact, I have arranged for an experiment which will demonstrate it. The glass tank before you is filled with water to the level of the mouth of a siphon, the end of which in the water is depressed and turned up again for the purpose of keeping it full. As soon as the water is at the level of the upturned mouth the siphon will cease to act. We shall place in this tank a model of a small steamer, and collect the water which overflows from the tank, that is the model's displacement. This we shall place in one scale of a balance and the model in the other, when you will have the opportunity of seeing that the two balance each other, as nearly at least as is compatible with the roughness of our experiment.

If we tow any vessel unsupplied with motive power, we shall experience a resistance due to the difficulty of dragging it through the water, and increasing with the increase of the speed at which we drag it. This resistance could be measured in pounds weight by attaching the tow-rope to a dynamometer, and by reading off the resistances at the various speeds. We would find these resistances varying for different speeds in the same vessel for different forms of vessels at the same speeds and for the same form of vessel of different sizes. Such experiments were actually carried out by the late Mr. Froude, in one case by towing a full-sized ship (the *Greyhound*) in deep water, but generally by a less expensive method in towing models along the length of a tank. Model experiments had been made before Mr. Froude took this matter of the resistance of vessels in hand, but it was not till his time that we were enabled to relate accurately the resistance of a model to that of a model of larger size, or to that of a full-sized vessel. Partly by speculation and partly by experiment, Mr. Froude discovered the law of this relationship; and as it underlies much of what I shall have to treat further on, it is important you should get some idea of it. What Mr. Froude discovered amounts to this: that for vessels of the same proportionate dimensions, and of the same form, or, as we say, of the same lines, there are speeds appropriate to these vessels which vary as the square root of the ratio of their dimensions, and that at these appropriate speeds the resistance will vary as the cubes of these dimensions. This seems at first sight a very complex statement, but a simple illustration will show you better the meaning of it than any amount of exposition. Supposing we had two steamers of the same form, the one 100 feet in length, 10 feet in breadth, and drawing 5 feet of water, the other 400 feet in length, 40 feet in breadth, and drawing 20 feet of water. Then the ratio of the dimensions of the larger steamer to that of the smaller one would be as 4 to 1. This will be apparent when you notice that the length, the breadth, and the draught of water of the smaller steamer is in each case one-fourth of the length, the breadth, and draught of water of the larger steamer. What Mr. Froude would have predicted of these two steamers is, that if the speed of the smaller steamer were ten knots, then the similar appropriate speed of the larger steamer would be 20 knots, because the square root of 4, which is the ratio of their dimensions, is 2, making the appropriate speed of the larger steamer twice that of the smaller one. At these speeds Mr. Froude proved that the resistance, with some allowance, would be as the cube of the steamers' dimensions, which means practically that the resistance would vary as the displacement of the two steamers. Therefore, by making the one steamer four times as long as the other, keeping the form and proportions otherwise the same, you could double the speed of the larger steamer without having any more resistance per ton of her weight than in the smaller steamer. This law shows us further that the resistance of the large steamer at the same speed as the small steamer would be, per ton of her displacement or total weight, very much decreased. Thus, in the same type of steamer, by simply increasing all the dimensions proportionately, the same speed can be obtained with much less resistance per ton of weight driven through the water, that is, since the speed remains unchanged, much less expenditure of horse-power, and consequently much less expenditure of coal per ton of weight driven. Judging from one case which I have in view, the resistance per ton of displacement, at 10 knots of the 400 feet steamer, would be only one-tenth of the resistance per ton of displacement of the 100 feet steamer (*i. e.*, 10 tons of displacement of the larger steamer could be driven for the same power at the same speed as one ton of the smaller steamer). This fact has discovered itself practically to many shipowners and shipbuilders who have very little knowledge of Mr. Froude's great work; and, at the present moment, as I shall have occasion to show further on, under the influence of this law and some other considerations, the average size of heavy cargo-carrying steamers is steadily increasing.

It is important that we should have some knowledge of the elements composing the resistance of a steamer. Mr. Froude has divided the resistance due to the dragging of a body, floating on the surface of the water, into three parts: The first of these is caused by the friction of the surface immersed in the water. The second by the formation of eddies or little whirlpools, such as you may see in the wake of a square-ended log, or behind the piers of bridges. The third is due to the formation of waves. That part of the resistance of vessels which is due to the friction of the immersed surface must, we know, increase with the amount of that surface, and will therefore be greater in vessels of larger dimensions than in those of smaller dimensions. It will, in similar vessels, be less in proportion to their displacement as they are increased in size, because, in the case of similar bodies, the larger they are the less is the ratio of the containing surface to the contents. We know further, that the frictional resistance increases not merely with the amount of the surface, but also with the nature of the surface. The rougher the surface the greater is the resistance due to it, and this is well exemplified in the increasing difficulty experienced in driving iron or steel vessels when long at sea, as compared with their condition when freshly out of dock. Of the formation of eddies and their share in the creation of resistance, we know almost nothing definitely beyond this, that they have some share in it; we do not know, however, what that amounts to, and are therefore obliged to include them in the third element of resistance, the formation of waves. This element increases in any steamer with the increase of speed, and in different steamers it increases with the unsuitability of their form for a given speed. The effect of wave-making resistance is prėdominant at high speeds, so much so as to greatly reduce at these speeds the proportion of the element of frictional resistance, as is illustrated in one of the diagrams before you.* The problem before the shipbuilder, in connection with resistance, is therefore for slow-speed steamers to diminish the amount of frictional resistance, both by making the surface to be driven as small as possible in extent, and by keeping it as smooth as possible; in the case of a high-speed steamer, by making the form of the vessel so suitable for the speed at which she is to be driven that the creation of waves may be as much as possible avoided. There is, of course, another element of resistance in that offered by the upper portion of the hull to being driven through the air, but of this it is extremely difficult, if not impossible, at the present time to take account. We shall, therefore, for the purposes of this lecture, assume that the resistances to be overcome are confined to the water in which the vessel is floating.

To overcome resistance it is necessary to develop power which may be applied to the vessel either externally by a towing-rope or internally by some mechanism of propulsion. Three of such methods have been advocated, and to a greater or less extent adopted in the present day, propulsion by the screw-propeller, by the paddle-wheel, or by a water-jet. We have to confine ourselves to the former method, and we shall now examine as shortly as possible what peculiarities are known to exist in the application of the screw-propeller to the propulsion of steamers. We know that if we were able to employ power perfectly we would require

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* See Plate II.

no more of it than that exactly equivalent to overcoming the resistance to be dealt with, which would amount to the resistance in pounds multiplied by the speed of the vessel in feet per minute, and if we wished to reduce it to horse-power, divided by the ordinary divisor for that purpose, 33,000. This expression of power is what is known among naval architects and marine engineers as effective horse-power, that is, the actual amount utilized in propelling the steamer, apart from all other considerations. The power developed in the cylinders of the steam-engine driving the vessel is the mean pressure per square inch on the pistons of these cylinders, multiplied by their area in square inches, and by the travel of the pistons in feet per minute, and divided by 33,000. This is what is known as indicated horse-power, and is practically the measure of the consumption of coal in any given steamer. Now, you may be astonished to hear that while the indicated horse-power developed in the cylinders of a given steamer may amount to, let us say, 3,000, the effective horse-power known to be necessary to propel that steamer at the given speed is perhaps only 1,500, or even less. There is thus, between the power developed in the cylinder and the power actually devoted to driving the steamer, what practically amounts to a loss of one-half. In some cases the loss is known to have amounted to a great deal more, and it is very rarely that any steamer is propelled with a less ratio between the effective and the indicated horse-power than that of one or two. The diagram* before you indicates in as plain a manner as it is possible to do the known ratios between the effective and indicated horse-power in the screw steamer *Merkara*, which was built by my firm and progressively tried on the measured mile, and also tried as a model by the late Mr. Froude. I may mention that in the case of one very fast merchant steamer, built by my friends Messrs. A. & J. Inglis, which was carefully tried progressively and also as a model by Mr. R. E. Froude, who has worthily succeeded his able father in the charge of the Admiralty Tank at Torquay, it was found that the effective horse-power was 60 per cent. of the indicated. This is an unusually high figure of efficiency, to some extent due to the circulating pumps being driven by a separate engine, not included in the indication of power, but it is exceeded in some of the torpedo-boats built by my friend Mr. Yarrow, where the effective horse-power amounted to three-fourths of the indicated horse-power. In these torpedo-boats the gross indicated horse-power is diminished by the air, circulating, and feed pumps being driven by a separate engine not indicated on trial, of which the power was, therefore, not included in that of the main engines. This is an unusual practice in either the mercantile or Government service, Messrs. Inglis's steamer forming an exception. Even allowing for this, however, the efficiency of the torpedo-boats' engines still remains wonderful, and if it could be

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* See Plate III.

reached in large work would produce either great economy of fuel or a great increase of speed. It may be due to the high speed of the engines, coupled with the admirable position of the propeller both vertically and lengthwise, its shaft coinciding aft with the keel, and its boss being fixed abaft the rudder; also to the great care taken in thinning, sharpening, polishing, and finely adjusting both the pitch and balance of the propeller. I believe Mr. Froude is investigating these wonderful results, and that it is probable experiments on full-sized torpedo-boats may be carried out, similar to those on the *Greyhound*, for the purpose of tracing its causes.

The late Mr. Froude has summarized the loss of power which we find in the difference between the effective and indicated horse-power under five heads: The first of these is due to the augmentation of the ship's true resistance by the action of the propeller. The propeller, in acting as a pump throwing a column of water astern from the reaction of which the steamer is driven ahead, creates a disadvantage to the hull in withdrawing stern pressure from the after part of the steamer; that is, pressure which, if the vessel were towed or were driven by paddle-wheels in the middle of her length, would be acting in her favor. The second element causing loss of power is the friction due to the screw-blades. This can be reduced by carefully sharpening and polishing these blades, and by as much as possible, with regard to the efficiency of the propeller or propellers, reducing the diameter, and thereby diminishing the velocity through the water of the outer ends of the blades, or, as in the case of the *Iris*, by actually diminishing the number of the blades to two, a practice which is also followed in the torpedo-boats. The third element in the loss of power is what is known as the initial friction of the engines; that is, the amount of power which would be consumed in turning the engines and shafting, supposing no propeller were at the end of the shafting. The fourth element is that of the additional friction due to the working-load on the engines when the vessel is being propelled; and the fifth is that due to the work done by the air, feed, and circulating pumps. Knowing the difference between the indicated and effective horse-power, and knowing also the various causes which produce this difference or loss, it must be acknowledged that any means by which this can be checked, and comparisons made between one steamer and another, must be of great value. It is evident that the first step in checking the amount of this loss and getting at the items which form it is to obtain a definite knowledge of the effective horse-power required to drive each steamer under her trial conditions, and it may be safely said that only by means of tank experiments can this be accurately discovered. On this account my firm resolved to establish an experimental tank for the purpose not only of enabling us to predict the speed of steamers of new types, but also for the purpose of carefully analyzing the trial results obtained from steamers actually built. I believe it is possible, by careful experiment, study, and collation of the results of various experiments, to obtain such a definite grasp of the loss between the effective and indicated horse-power as will materially help us to reduce the percentage of this loss. Should this be attained, it is equivalent, in a given steamer, either to increasing the power developed in her for a given consumption, and thereby increasing her speed; or, at the same speed, to diminishing the power, and thereby diminishing the consumption.

Before proceeding to examine the tabulated results now before you, it is well that you should have some definite understanding of the meaning of the numbers by which they are expressed. The first column of the percentage ratios in the tables is devoted to what is called the ratio of the displacement to the containing prism, expressed usually in decimal fractions, and is generally known as the prismatic coefficient of displacement. As, however, you will more easily follow such coefficients expressed in percentages, I have reduced not only this one, but the others, to that form. Now, the prismatic coefficient of displacement is the ratio between the actual displacement of a steamer at a given mean draught and the displacement of a body of the same length and the same midship section, but having that midship section carried from end to end in a prismatic form. As the relations of these two displacements can be more easily explained by demonstration than by mere words, I have arranged for a suitable experiment. There is before you a trough of prismatic form,* the section and length of which correspond with the midship section and length of the models already referred to. This trough is filled with water up to the water-line of the model to be placed in it. Pouring out this water into a vessel with transparent sides, and of uniform section throughout its height, we shall mark off the surface of the water as 100, dividing the distance between this and the taps for running off the water into as nearly as possible 100 parts. Pouring the water into the prismatic trough, if we now place the model in the trough and force it down to the water-line, the overflow will represent the displacement of the model. When this overflow is poured into the vessel already referred to, the height at which it stands will represent the number of 100th parts which it is of the total water in the prismatic trough; that is, the percentage of the water in trough occupied by the model at its line of flotation.

At the extreme right hand of the tables you will find a series of columns devoted to what is called Kirk's analysis. This is a method of analyzing the form of any given steamer of which we possess the length, mean molded draught, displacement, and area of midship section, and was invented by Mr. Kirk, a marine engineer, of whom the Clyde has good reason to be proud. For a detailed description of this most ingenious method of roughly representing the form of a given steamer and comparing it with that of another, I must refer you to a paper read by its author before the Institution of Naval Architects. The method

* See Plate IV.

amounts to this: that the steamer to be analyzed is supposed to be reduced to a form of the same length, having a depth the same as the draught of water, having a breadth equal to the mean breadth of the midship section, *i. e.*, the area of the midship section divided by the draught, and having the two ends equally sharpened in a wedge form, so as to reduce the displacement of the form to that of the actual ship. Having obtained a form of this kind it is quite evident that we can gather from it the value of the mean half breadth, which is called B in the tables, the length of the sharpened portion at each end, which is called A, the length of the parallel portion of the middle body, which is called C, the angle, or rather the half-angle of the sharpened portion, which is given in the tables, and what would be the wetted surface of such form, which is given under the head "surface." As this approximates pretty closely to the actual wetted surface, it gives a fair idea of the amount of resistance in each steamer due to surface friction. Table 5 gives the particulars, and Plate V shows the forms, set off as above, for some of the Clyde steamers. I have added a Government vessel, a torpedo-boat, and a steamer built on the East Coast, for contrast. We now come to the comparison of the different steamers of which we have particulars, and to the induction from them of such hints as may be of service to us. But, before taking up this, I desire to acknowledge my indebtedness to Mr. James Laing, of Sunderland; Mr. Edward Withy, of West Hartlepool; Mr. Wigham Richardson, of the Tyne; and Messrs. A. & J. Inglis and Messrs. J. & G. Thomson, of this district, who have all, with great readiness and kindness, afforded me the information from which, in combination with some supplied by my own firm, these tables have been prepared. It is matter for much congratulation, when gentlemen so widely separated, and working in such varied developments of the ship-building industry, have the heart to afford such valuable information as I am enabled this evening to place before you. Nothing can speak better for the future of ship-building than the display of such a spirit. Besides my indebtedness to these gentlemen, I have to acknowledge further my indebtedness to Mr. Yarrow, of Poplar, the celebrated torpedo-boat builder, who has supplied me with the information regarding the fast torpedo-boat mentioned in the tables. This vessel is, I believe, the fastest steamer at present afloat in the world, and the information supplied by Mr. Yarrow is all the more to be valued, not only on account of its accuracy, but also of the great readiness with which he afforded it from a business which is essentially a speciality, and in which the competition is more one of ingenuity and daring than of ordinary financial considerations.

You will notice that the weights comprising the light displacement or total weight of the steamer ready to receive her load of cargo, and coal, &c., are divided into three quantities.* First, the net weight of iron or steel in the hull. Although this weight is not completely struct-

* See Tables 1, 2, 3, 4.

ural, still it is so much so that we may call it the structural weight. Second, the weight of machinery, that is, of engines, boilers, shafting, and propeller, as placed on board with steam up; and, thirdly, the weight of wood-work, outfit, and other items clear of stores, comprising the remainder of the weight of the ship. On the tables before you, to prevent their becoming too unwieldy, these weights have not been given, but their ratios to the displacement, which is the information we most require.

You will notice that for the East Coast and also for the Clyde steamers two sets of tables are given, one for the steamers with their draughts as fixed, and given to me by the builders;* the other tables with all the draughts brought to the common ratio of 55 per cent. of the molded breadth.† It is with the latter tables that we shall have, and for reasons which will be explained further on, principally to concern ourselves. Taking the East Coast steamers first, that is, those built on the Tyne, Wear, and at Hartlepool; they are divided into two classes, those with upper decks continuous, and those with quarter-decks. This is a real distinction prevalent on the East Coast. The quarter-deck steamers, you will observe, do not exceed 264 feet in absolute length, nor 7½ beams in relative length, and their average speed is only about nine knots. Both of them and of the other class of steamers the means of their percentage ratios have been added to the table, so that we may more easily compare them *en masse*. Making this comparison, we see that while the continuous-decked steamers have a mean molded draught ratio to the beam of 57.8 per cent., the quarter-decked steamers have only a ratio of 53.2 per cent. This is the key note of the difference of the two classes, and arises from the fact that the quarter-decked steamers are almost invariably employed in trades having very limited draughts of water. As a consequence, the utmost possible has to be got out of them under those conditions, and this is done by making them, to begin with, of very much less absolute length and smaller proportional dimensions, of greater fullness, as is shown by the mean prismatic coefficient in their case being 78.3 as against 77.2 per cent., which, considering the difference in proportional draught, is fuller even than it looks, and by sacrificing to some extent the weight of machinery employed, there being only 4.8 per cent. of the displacement utilized for this purpose, as against 5.3 in the continuous-decked vessels. The percentage of the displacement devoted to structural weight is 22.4 per cent. in the quarter-decked steamers, as against 21.7 in the others, and this arises partly from the less molded draught giving a less fair proportion of displacement, and also from the non-structural iron weights bearing a larger proportion in small than in large steamers. The same remark applies to the weight of wood-work and fittings, which, you will observe, average one percentage more in the quarter-decked steamers

* See Tables 1 and 2.

† See Tables 3 and 4.

than in the others. These weights bulk more largely for a similar fineness of steamers in small than in large steamers. You will observe that the average length of the continuous-decked steamers only comes to a little over 280 feet, and their proportional length is under 8 beams, the maximum proportional length not exceeding $8\frac{1}{4}$ beams, and the minimum being $7\frac{1}{5}$ beams.

Coming now to the Clyde steamers, we shall, for the purposes of direct comparison with those built on the east coast, take up first that table concerning them in which their draughts are brought down to a common proportion of the beam of 55 per cent., and we shall compare the results obtained from this table with that of the East Coast steamers at a similar proportional draught.* After doing this, and gathering from the comparison such lessons as are obtainable, we shall proceed to examine the table of Clyde steamers with the varied draughts as given by their builders. Among the nine steamers given as representing to a fair extent the varied work done on the Clyde, there is one which, in so far as the percentage ratios are concerned, we must deduct from the table, that is, the steamer R. This vessel is to all intents and purposes, although built of steel and fitted for a fair number of passengers, simply a magnified East Coaster. Deducting steamer R, we have, starting from a displacement taken in the case of all the steamers at a draught equal to 55 per cent. of the molded breadth, the following comparison between the average ratios of the Clyde steamers and those of the East Coast. From this comparison we exclude the quarter-deck steamers, as their draughts could not be increased. In speaking of these steamers I am quite aware that many of them, especially of those built on the Clyde, are not built for weight carrying, and that averaging their results over such variations of size is a very rough method, but we are compelled to employ it owing to the shortness of time at our disposal. We find, then, that the average prismatic coefficient of the Clyde steamers is 71.3 per cent., as against 76.7 per cent. in the East Coast steamers, a very marked difference. Taken upon the displacement, the average percentage of the structural weight is, in the case of the Clyde steamers, 27.7, against 23 in the East Coast steamers, and of wood-work and other weights 11.5 in the Clyde steamers, against 6.17 in those of the East Coast, and of the machinery weights 10.8 in the Clyde steamers, as against 5.6 in the East Coast steamers, the ratio of the total weight of hull and machinery to the displacement being in the Clyde steamers 50 per cent., and in the East Coast steamers about 35, meaning that the former only carry of dead-weight capacity 50 per cent. of their displacement, while the latter carry 65 per cent., that is, 30 per cent. more. This is an enormous difference in carrying power, and it is our business to discover from the facts before us the causes which give rise to it. Taking, then, first the machinery weights, we can see that the greater ratio which they bear to the displacement in

* See Tables 3 and 4.

the case of the Clyde steamers, as compared with those of the East Coast, is simply due to the greater power employed and the greater speed attained. So long as these speeds are required this can be diminished by no method excepting by proper adjustments of power to the form and size of the steamers. Pretty grave mistakes are not infrequent in this matter, especially in fast steamers, power being sometimes wasted on an unsuitable form, and displacement being sometimes wasted in a form being rendered too fine for the power contained in it. The greater ratio of the wood and other fittings to the total displacement in the Clyde steamers, which amounts to nearly double, is due to their generally being fitted for passengers, and consequently having wood decks and such other fittings as are required for this trade. Any reduction in these weights could only come from owners reducing their requirements. There are other cases in which they could do this without diminishing the comfort of their passengers, and they would thereby diminish the first cost of the steamer, and increase her money-earning margin. We now come to the most important of all these ratios, that is, the ratio of the structural weights to the total displacement, which we find in the Clyde steamers to amount to 27.7 per cent., as against 23 per cent. in the East Coast steamers. In order to eliminate the influence of the greater bulk of displacement in the East Coast steamers in producing this ratio, there is appended to their table a readjustment of these ratios to a prismatic displacement coefficient of 72 per cent., assuming the structural and other weights to remain the same. Starting from this basis, we have the average structural weights in the East Coast steamers amounting to 24½ per cent. of their displacement, as against 27.7 per cent. in the Clyde steamers; but when we remember that of the total displacement tonnages of the Clyde steamers fully 65 per cent. has the advantage of being constructed of steel, the difference is much greater than it appears, and ought really to be at the least the difference between 24½ per cent. and 30 per cent., allowing for the steamers built of steel being assumed of iron. What are the causes of this great difference in the ratio of the structural weights of the East Coast steamers as compared with those of the Clyde? In my opinion there are three causes: First, the greater power of the engines in the Clyde steamers, and their passenger accommodation, two things which, besides increasing the wood-work and odd weights, always involve an addition to the iron used in the ship. The increment due to this cause must, however, be very small. Second, there is an increment of structural weights due to the fact that the Clyde steamers are generally deeper in proportion to their breadth than East Coast steamers. It is difficult to say for how much this feature would account. Although it would account for some of the difference, and more than the first cause mentioned, it would not account for even a large fraction of it, because in some cases this greater depth is absolutely required to meet the strains due to greater absolute and proportional length, and if it were diminished the structural weights in such cases would probably not be diminished, but might be increased. We now come to the third set of causes, and they are, I am convinced, the real and important ones. The tables show them at a glance. They are the absolute and relative length of the Clyde steamers as compared with those of the East Coast. A rough average of the Clyde steamers we have been considering shows an absolute length of 382 feet and a proportional length of 9.23 beams, as against 281 feet and 7.85 beams in the case of the East Coast steamers. On both of these accounts a higher figure for weight is to be expected. In the first place, absolute size alone involves scantlings increasing more rapidly than the dimension, and therefore weights increasing more rapidly than the displacement. And, in the second place, decrease of section involves increase of scantlings; so that in two steamers of the same length the weights, as compared with the displacement, will bear a larger ratio in the case of the small section than in the case of the large section. We have thus exemplified to us by these tables the effects of great physical laws, and although in detail the scantlings are not in my opinion as well adjusted as they might be, still by the test of experience they are sufficiently so to enable us to rest our trust upon the induction just drawn, especially when we know it is confirmed by theory. Taking the individual steamers mentioned in the table,* and excluding steamer O on account of her abnormal proportional depth, and an equally abnormal use of iron in her for non-structural purposes, and steamer U, because her owners actually overbuilt her, and placed her thus altogether outside the rules of common practice, and steamer W on account of her extreme fineness and special arrangements, we find that the steamer of the greatest absolute and proportional length, viz, V, is very much heavier, not only than the steamer P, but also than the steamer Q, built of iron, and coming near her in proportional length. The steamer V is, however, light for her dimensions, and shows the confidence of her owners in steel. It is difficult in considering individual steamers to trace tendencies so fully in their case as we can in averages, but I may inform you that the percentage of the displacement employed for structural weights in steamer V is considerably exceeded in a steamer of greater absolute and relative dimensions employed in the same trade but built of iron. As showing the value of moderate proportional dimensions in reducing weight of structure you cannot have a better example than steamer R; although, as compared with the East Coast steamers of greater absolute length, the percentage of displacement required for her structural weights is as 20.9 per cent. as compared with their average of 23 per cent. Were this steamer built of iron instead of steel her percentage would be about 23.8 as against the East Coast 23, showing an increase due to her increase of absolute length. Her moderate actual percentage arises, as you will observe, from the use of steel.

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* See Table 3.

While speaking of the subject of weights, it may be worth while to point out to you, not merely the percentage of the displacement in each steamer devoted to machinery weights, but also what can be done with a given weight of machinery in developing horse-power.

If you refer to Table 6 you will find a statement not only of the average, but of the exceptional results obtained up to date in this way, and you will see from it that while the development of power varies with the ordinary type of engines, from about 5 horse-power to the ton weight of machinery up to 6, in vessel W as much as 6.5 horse-power per ton weight has been developed; in the "*Nelson*" class, already referred to, 6.6 horse-power per ton weight, and in the "*Iris*" about 7.5. In Mr. Yarrow's torpedo-boat, with extremely light, fast-running machinery, and the help of the forced blast, the development of power reached the astonishing rate of 36 horse to the ton of weight.

Before leaving this portion of our subject, I desire to call your attention to the Government dispatch vessel and fast torpedo-boat, of which particulars are given in Table 1. You will notice that both are extremely fine, having a prismatic coefficient of 56.5, at a draught in the Government vessel having a ratio to the beam of 40.9, and in the torpedo-boat of 26.9 per cent. The amount of their displacement devoted to machinery is, in the Government vessel, 27.1 per cent.—a very large increase upon anything in the merchant service; and in the torpedo-boat, 42.4 per cent., an enormous increase, viewed from the side of power, when it is remembered that these torpedo-engines develop per ton of weight five times as much power as the Government engines. This will sufficiently show you the extraordinary nature of the torpedo-boats as compared with any other steamers afloat. The structural weights, which in the Government vessel amount to 28.2 per cent., in the torpedo-boat amount to 35.5 per cent. This seems to indicate very heavy methods of construction, whereas, really, the very opposite is the truth. Both are extremely lightly-constructed vessels, but in both the ratio of draught to beam is, as compared with merchant steamers, extremely small, and, further, the dimensions multiplied together are of very great amount as compared with the displacements.

This shows that a comparison on a displacement basis, like most other methods of working, needs to be conditioned and qualified by other considerations if it is to be of much value. Indeed, the only percentage of the displacement basis which has any reliable value for purposes of comparison in various types of steamers is that of the weight of machinery, as the displacement represents the mass of the form to be driven, and has, therefore, a relationship to the weight of the machinery. Even this, however, must be conditioned by the efficiency of the machinery in developing power per ton of its weight.

Perhaps one of the most marked peculiarities in these tables is the extent to which absolute size permits of what we at present call high rates of speed, without much consideration of fineness. In Table No. 1

this is shown roughly by the difference between the sea-speeds given for the different steamers; for example, steamer S, with a prismatic coefficient of 65.7 per cent., is only a steamer of 14 knots average at sea, while steamer U, with a prismatic coefficient of 72.4 per cent., has a sea-going speed of 15 knots, and steamer V, with a prismatic coefficient of 71.1 pei cent., has a sea-going speed of 17 knots. These differences of speed arise from this—that fineness is overmastered by size—steamer S having a displacement of 3,297 tons, steamer U of 8,200 tons, and steamer V 12,450 tons. This peculiarity is further demonstrated in Table No. 5, deduced from actual trials where, while steamer S, with a prismatic coefficient of 62.3 per cent., requires 1.2 indicated horse-power per ton of displacement to do 15.4 knots, steamer O, with a prismatic coefficient of 68.7 per cent., only requires .96 of an indicated horse-power per ton of displacement to do 15.9 knots, and steamer U, with a prismatic coefficient of 68.9, does 15.67 with .834 indicated horse-power per ton of displacement, the comparative displacements of these three steamers being 2,425 tons, 5,405 tons, and 6,125 tons. In connection with this table, I may remark that the best result I have ever known in any sea-going steamer, either belonging to the mercantile marine or the Royal Navy, is that attained by steamer W, in which, with a displacement of 2,441 tons and a prismatic coefficient of 63.5, a speed of 15.2 knots was obtained with .938 indicated horse-power per ton of displacement. The Government dispatch vessel X, shown on the same table, is an example of what a high rate of speed can be obtained in a sea-going vessel of moderate length by the application of a considerable amount of power. This vessel had a length between perpendiculars of only 300 feet, but by giving her an extreme fineness of form, represented by a prismatic coefficient of displacement of 54.8 per cent., and allowing 2.3 indicated horse-power per ton of displacement, a speed of 18.6 knots was obtained. The same principle is still further developed in the fast torpedo-boat Y, where, with a prismatic coefficient of 56.5 per cent., actually fuller than that of X, and with an absolute length of only one-third the amount, by the application of what might be called a tremendous rate of power, 15.4 indicated horse-power to the ton of displacement, a speed of 22.5 knots was obtained. From this table we may gather that with steamers of ordinary fineness increased size of the same type will not only, as we have already seen in the early part of this lecture, disminish the amount of indicated horse-power per ton of displacement required to drive them at the same speed, but will, which is practically equivalent to the same thing, drive steamers of greatly increased size, and of less fineness, at higher rates of speed, with less indicated horse-power per ton of displacement than smaller steamers of greater fineness; and from the same table we learn that where the prismatic coefficient of displacement does not exceed 57 per cent., steamers of even moderate size and fair proportions may be driven at great rates of speed by larger applications of power.

The point, however, to which I wish to call your attention most emphatically at this time, as deduced from these tables, is the relationship which they demonstrate to exist between the draught of a steamer and her breadth of beam. This has been partially illustrated by our having been compelled, for the purposes of a fair comparison, to bring all the steamers in question to draughts which would bear a common ratio to their breadth molded, and it is further practically exemplified by the well-known anxiety of unscrupulous owners, in as far as lies in their power, to increase the ratio of the draughts of their steamers to their breadths. But this point is even more forcibly exemplified. Loaded to 25.17 feet, the large steamer V has only available for carrying 39 per cent. of her total displacement.* Were she loaded down to 28 feet 6 inches molded draught, or 55 per cent. of her molded breadth, a fair loading draught for ordinary steamers, the percentage of her displacement available for dead-weight carrying would be raised to 48.3,† an increase of more than 25 per cent. upon her actual dead-weight carrying. This increase in her case may, from the amount of cabin accommodation fitted in her, not be necessary to meet the requirements of her measurement capacity; but were it necessary it could not be obtained because, I understand, the port from which she sails cannot afford a draught for easy working of more than 26 feet. That draught is intimately related to beam was observed at the end of last century by that most able naval architect, Chapman—but I am sorry to say this point has been of late much overlooked and forgotten, and, as a consequence, many have failed to interpret either the causes which have induced some of the abnormal developments of the proportionally extremely long steamers, or, what is of more importance to understand, the disadvantages as well as the value of increase of beam. Two or three years ago the ship-building world swore by 10 beam steamers, and the fashion became a matter of dogmatic ship-building orthodoxy that there was little probability of success for any steamer under 9 beams in length. At the present moment the dogmatic orthodoxy has taken another, and, unless under conditions, a more unreasonable turn. No steamer is now supposed to be rightly proportioned unless she is a broad steamer. For my own part I think I prefer the first dogmatic orthodoxy, because it is dependent in reality upon the restriction of draught of water, although it is quite probable that those who brought it into fashion had no conception of the cause controlling them. Increase of beam for the purpose of obtaining greater fineness of form is, where great speed alone, or principally, is in question, the method of fining a steamer which makes least increase of her wetted surface, and, consequently, of the frictional element of her resistance; but if the draught of water is restricted, and we go to large sizes of steamers, in most circumstances it is better to increase length than breadth. The Suez Canal and the comparatively restricted draught of

* See Table 1; 100 less 61.0. † See Table 3; 100 less 51.7.

water in the Atlantic service at the terminal ports, legitimately fostered this tendency, but there is no doubt it has been carried much too far with sizes of steamers and draughts which did not require it. The present fancy for beam as a dogma is built upon less fact and rather more theory, and it is a very curious thing that one company, which has pursued this idea unreasonably, has been quite unable to obtain from it any advantage in speed, which was the aim they had in view, instead of increasing dead-weight capacity. It would be well if owners clearly understood that a steamer of 55 feet molded breadth must have, as a minimum for all-around efficiency, a molded draught of about 28, or, if she were to get full justice, say 30 feet, and a steamer of 60 feet beam should have a minimum molded draught of 30 feet, or, better, of 33, supposing the vertical disposition of weights in hull, the freeboard, and amount of rigging, sails, and spars to be as in the average merchant steamer possessing sufficient stability. That there are some dock proprietors who have received wiser advice upon this point than many ship-owners is evidenced by the fact that the new docks which it is proposed to construct at Tilbury, on the Thames, are to have clear draughts of water of 30 feet and upwards. Steamers are increasing in size, and the least costly increase for weight carrying, and up to certain points for speed, is in beam, provided sufficient draughts can be obtained. Steamers will follow their natural course of development, and it will be for dock proprietors, river trustees, and harbor boards to see that their docks, rivers, and harbors are of such depth as to permit them to favor steamers so developed. I believe it is found daily more difficult to build the larger types of Atlantic steamers rigid enough for the service, even with the great percentage of their displacement devoted to structural weight. A reaction will set in against their extreme proportions and absolute length. When this happens, beam will be increased, as a consequence draught increased, and distinct preferences accorded to ports having great draught of water. No local influences can fight against such causes. When they are once clearly understood by ship-owners and the public they will become dominant, and ports, docks, rivers, and harbors will pass through a process of natural selection in which the fittest will ultimately triumph over the less fit. Besides, great draught of water and comparative shortness of a steamer are more favorable to the efficiency of the screw, by keeping it well immersed, than great length with shallow draught, which tells very much against the screw's efficiency. So important is this matter that the White Star line tried to overcome the difficulty by a mechanical arrangement. It can only be overcome by an increased draught of water, and forms thus another argument in its favor.

This matter of draught is of prime importance to the Clyde and to the trustees of the river Clyde. At the present time they are congratulating themselves far too securely upon the condition of the river. They have a good right to do so in so far as they look back upon the great labors by which they have attained their present position, but, with regard to the future, the sooner they make up their mind that, if they wish Glasgow to remain a first-rate shipping port for the larger class of steamers, the Clyde must be greatly deepened, the better it will be for the whole district. In any case the town of Greenock, being at the mouth of the Clyde, and having no length of approach to deepen, should hold a first-rate position in the future, provided they do not make their dock entrances too narrow and too shallow for its requirements. We are on the verge of changes in naval architecture which will give great advantages to ports lying near the sea and with great facilities of draught of water. Steamers are increasing in size on the average at a much greater ratio than the ordinary world has a conception of, as is demonstrated in Table 7, showing the average tonnage of the steamers launched on the Clyde, Tyne, Wear, and Tees for the last three years. A glance at that table shows that increase in average size is not confined to any one port, but is universal. The increase in this respect is rather obscured in the Clyde district by the fact that so many specialized small steamers, yachts, both steam and sailing barges, and light-draught steamers to be shipped in pieces, are built on the river, thereby reducing the average; but in spite of this the average continues to increase, and if we wanted any further demonstration we might get it in the case of the *City of Rome*, the *Servia*, and the *Alaska*, although, personally, I do not think that either of these three steamers is the type of the future for speed or cargo-carrying. You will notice on this table that of the tonnage launched on the Tyne, Wear, Tees, and Clyde for the three years, the latter river absorbs a steadily increasing percentage, a matter which should be of some comfort to any who may, two or three years ago, have been despondent about the future of our river.

Having now explained to you the general principles underlying the consideration of the speed and dead-weight carrying of screw steamers, and having further demonstrated to you in as far as the amount of facts at my disposal and their complexity permit the practical influence of these principles, it remains for me to speak to you upon the possibilities of the future involved in their application. We have to ask ourselves what can be done in the future in increasing speed upon the one hand or dead-weight capacity on the other, or both, subject to such economical conditions as may render them financially possible. Financial considerations must in all cases influence the naval architect in his consideration of such important questions. They form that discipline by which any redundancy of mere fancy or theory may be restrained within proper limits. We know that, provided the form and fineness of the steamer are suitable, the speed can be greatly increased by the proper application of greatly increased power. This has been demonstrated in the case of even the comparatively small torpedo-boats, where the application of great power has surmounted the difficulties of driving a vessel of small dimensions. To apply more power to a vessel without abnormally increasing the weight of that vessel, or, what comes to the same thing, without increasing the weight of coal to be carried for a given distance to be run, is the problem before us. At the present moment there is proposed a method of diminishing the coal consumption required for a given development of power, and there is being fitted by Mr. A. C. Kirk, in the screw steamer *Aberdeen*, machinery from which it is hoped that a great economy in coal consumption will be produced, as compared with the results obtained in practice from the present compound engine. The principle involved is that known as triple expansion—that is, expansion through three cylinders successively instead of through two, as in the case of a compound engine, a much higher pressure (I understand 120 lbs.) being employed. By the triple expansion the variation of the temperature of the steam in each of the cylinders through which it passes on its way to the condenser is reduced. Should this further application of the principle of expansion be successful—and there seems good reason for hoping that it will be so—we shall be enabled to cross the Atlantic developing a given power with a displacement reduced by the amount of coal which will be saved in the voyage. This is what might be called an indirect method of saving weight; but two other direct methods of saving machinery weights are also attracting the attention of the technical world. Both of them are combined in the torpedo boats turned out by Messrs. Yarrow & Co. and Messrs. Thornycroft & Co.; one is by employing only the strongest materials, and in the smallest proportion, in the construction of the engines; the other is by reducing the size and weight of the boiler by the employment of the forced blast; that is, by employing a boiler of the locomotive type instead of the ordinary marine type. The former of these methods has been exemplified upon a larger scale in the type of engines lately introduced into the Admiralty, and of which the first was designed by Mr. Kirk, to whom reference has already been made. These engines were fitted in the *Nelson*, and were, as compared with the engines of a sister ship, constructed by another engineering firm, which developed less power, 115 tons lighter. Not being an engineer I cannot speak with the fullest authority upon questions of the probability of economy of weight and coal consumption, but I understand that the economy in the weight of engines does not affect the chances of economy in consumption, whereas up to date the economy in the weight of boilers as applied to torpedo boats has not been productive of such economy as can be obtained without the use of a forced blast. It would seem, therefore, that in so far as we can hope for a combined economy both in weight of machinery and in the consumption of coal, we must confine ourselves to such expectations as may be fulfilled by the employment of stronger materials and lighter design in the engines, by the use of steel, and a higher pressure in the boilers, and by the further development of the division of expansion, now being attempted by Mr. Kirk.

Of course, in the case of steamers having only very short runs, where the weight of coal to be carried would not be of great amount, the forced blast might be employed with decided advantage in reducing the weight of the machinery, and thereby reducing the total displacement to be driven.

Granted, however, that we had attained the maximum economy of weight of machinery and the maximum economy in weight of coal to be carried, we have still to ask ourselves what other conditions are involved in carrying out such an improvement as there would be in placing fast express steamers on the Atlantic capable of crossing that ocean between the States and this country at an average speed of twenty knots an hour. This problem is the subject of much speculation and discussion at the present moment, but so far it has seemed to me that the speculation and discussion has only arrived at the preliminary stage. It has been said that the thing should be done, and it has also been said that the thing is possible. Both these statements are, in my opinion, correct, and we have every reason to expect that at no very distant date the problem will be solved. Before it is solved, however, if it is to be solved subject to financial considerations likely to insure success, a great deal more work will have to be done than in simply making probable statements. I have already touched upon the help which we are likely to receive from the marine engineer, and it is now proper that we should consider what part the naval architect should play in the matter. Having secured machinery of the lightest possible practical weight for the power to be developed, and at the same time of the highest possible present economy, we have to get a hull of such strength and rigidity as shall sustain both the sea strains to which it must be subject and the vibrations due to powerful machinery and propellers. We may decide at once that the material to be employed is steel, as being that from which we can obtain the greatest amount of strength and reliability with the least possible weight. We must further decide upon the dimensions of the steamer to be employed, and while in doing this, supplying a form of little resistance, we must, if possible, supply a form which will make the smallest calls upon us for weights of construction. I have already shown you that extreme actual length is unfavorable to the realization of such wishes. I am, therefore, convinced that the steamer which is to do this Atlantic work will be a vessel of what may be called at the present time moderate length; that is, a vessel which will not only be shorter than the *City of Rome*, but shorter than the *Servia*, and shorter than the *Alaska*, which, of the three steamers, as far as I can learn, comes nearest the type I have in view. I believe the steamer to do this work will be under 500 feet in length between perpendiculars. What her other dimensions should be would have to be fixed by experiment and very careful series of calculations. Having, however, decided upon our machinery and dimensions, there still remains the question of construction, and of this it may be said that if the vessel is not to be of enormous cost and overburdened with weight, she must be of a novel construction, and such as I believe the registration societies are not likely to pass, not because of any deficiency in strength, but because (although you may think this strange) of absolute deficiency in weight. From a long experience of submitting sections to Lloyd's, I find that the principle upon which they go is, that although a builder may propose an arrangement by which, at the same time, the weight of a certain portion of the structure is decreased, and its rigidity and strength increased, he is required to put the economized weight into some other portion of the structure, or to add it to some portion of the rearranged part, the principle being that no builder must be allowed to build a given ship of less weight than his neighbors, even although, by the application of his thought and intelligence, he can do this, not only without disadvantageous results, but with actual advantage. I am not going to blame Lloyd's Society, or any other registration society for this, because their duties are so delicate in the way of seeing fair play between one builder and another that they are obliged, even at the risk of efficiency, to adopt principles which shall secure them from the suspicion of any unfairness. This is one reason why the vessel we propose should not be built to class; but there is yet another, and it is this, that the function of the registration societies is not to initiate new systems of construction, but to sanction those already in existence, and to deduce from them laws for the construction of others of the same kind; in truth, as their name implies, they are formed not for the purpose of initiation, but for the registration of results already practically achieved. If at the present moment you desire to see material employed with the greatest economy, and at the same time completely fulfilling its purposes, you must not go to classed steamers, but you must go to torpedo-boat builders, to the wonderful light structures of the Admiralty, or to the equally light structures produced by private builders, free from the control of the registration societies, for light-draught steamers.

Of course, the ultimate decision on these matters rests neither with the registration societies nor with the builders, but depends upon owners. Are they prepared to take such a step out of the common, and to intrust such powers to the leading firms on this river, or in other parts of the country? If they are, we may hope very soon to see a reasonable and fairly economical accomplishment of this difficult problem. The owner has, however, even matters of greater weight than this to consider, and in which to take bold steps concerning the structure of the ship. The step I am going to recommend has been already taken by our own Admiralty in special ship structures, of providing in such for the weight of structure necessary to stand the strains of the sea, but in omitting the overweight of structure required for the purpose of providing local strength sufficient to allow of constant grounding and knocking about. This may seem a good deal to ask of an owner, but its rejection means that if he burdens the ship with the weight of structure to meet these requirements he simply increases his first cost, with the increased weight and size of the steamer, and consequently his current expenses in driving her. There is no reason why such a steamer should not be kept permanently afloat, excepting when she requires to go into the dry dock, by her coal and stores and passengers and light packages being taken to and from her by tenders. If I am not misinformed, this method of treating the larger Atlantic steamers is at present either partially or completely in practice at Liverpool, and it is, I know, partially in practice in the Clyde. A complete development of it would permit of the conditions required, and this would be all the easier because, for an express passenger steamer, the owner would have to sacrifice all idea of carrying cargo. This, among the various discussions and remarks upon this subject, is, I am happy to see, pretty well understood. Cargo carried in an express steamer would be about one of the most expensive luxuries—one might say fancies—that any owner ever indulged in, because every ton of it would be an increase of the displacement of the steamer, consequently of the difficulty of driving her, of her weight of construction, of the weight of the machinery, and finally of the amount of coal to be carried. It is not possible for me, in the limits of time at my disposal, further to develop this question, nor indeed am I prepared to do so without a much more laborious consideration of it than I have yet been enabled to give to the matter.

Express boats may, however, be used for other services than that of the Atlantic, where the distances to be traversed are less, and the weather less tempestuous. Using Mr. Froude's law, and starting from the results obtained in Mr. Yarrow's torpedo boat, given in Tables Nos. 1 and 5, although not of immediate importance, it is worth while speculating upon what the result would be of doubling and trebling the length of this boat, keeping the dimensions in the same proportion and the form unchanged. Assuming that in the event of such an increase the amount of indicated horse power were kept proportional to the displacement, and the weight of machinery per indicated horse-power were no greater then in Mr. Yarrow's torpedo boat, also that the weight of construction absorbed no greater percentage of displacement than in his boat, then a similar vessel 200 feet long by 24½ feet extreme breadth, 22 feet breadth on the water line, and 9.9 feet in depth and 5.9 in draught of water, would have a displacement of 308 tons, and might be expected to attain a speed of about 27 knots per hour. A similar vessel 300 feet long, 37 in extreme breadth, 33 breadth on water line, and 14.8 feet depth, and 8.9 draught of water, with a displacement of 1,040 tons, might be expected to attain a speed of 31 knots. I am only speaking of these as matters of speculation, but it is impossible to say that they may not be fulfilled, and they are within the bounds of possibility, provided engineers could produce in the 200-feet boat about 4,800 indicated horse-power, and in the 300-feet boat about 16,000 indicated horse-power as easily as Mr. Yarrow produced 620 indicated horse-power in his 100-feet torpedo boat. The highest of these developments of power is enormous, and fully 50 per cent. more than the promised development of power in the three large Atlantic liners lately built. We may therefore assume that we are not likely soon to have the idea of the 300-feet boat developed, but it would be risky to say that something approaching to the 200-feet boat may not very soon be attempted. There are services and purposes for which such speed would be very desirable, and the torpedo-boat builders have worked so steadily up to the 100 feet in length that it seems to me not at all improbable they may go still further, while it is possible they may be met by the larger builders working down to meet them.

As to the prospects of increased dead-weight carrying, it is not difficult to predict the probable line of its development. Experience shows that moderate proportions, low speed, and full form, combined with a draught bearing a great ratio to the beam, are the conditions of success in this class of steamers, and we may expect to see these conditions develop more and more. When they are so developed that their demand for draught presses upon the facilities generally offered, as restricted draught is at present forcing the large Atlantic steamers into disadvantageous forms, and thereby pressing upon them, you will see the meaning attached to draught in this lecture forcibly and practicably illustrated. In any case we may be sure the differentiation between fast steamers and heavy carrying steamers will become greater every year, as neither can compete with the other in its own specialty, and the trades in which this differentiation is going on will by its very operation make the cargo steamer more purely a cargo steamer, and the passenger and mail steamer more purely an express steamer day by day.

Whatever the results of these speculations may prove to be—and I do not wish to lay too much weight upon them—there is one thing clearly desirable, and that is, that we shipbuilders and engineers should be able to treat them in a practical and common-sense fashion. Now, common sense in naval architecture is simply the application of experiment and fact, and the deductions from them to actual work, whereas theory is the application of unverified opinions to the same work. Many shipbuilders are misled by the fact that it is quite possible to keep reasonably right while dealing with a uniform type of steamer, or one upon which only slight modifications are made. This is the condition of affairs on the northeast coast of England, and under it great technical successes have been attained by men who have very frequently received no thorough scientific training. They have attained their successes by small modifications, and what amounts practically to experimenting upon a large scale, or what is called by another name as the method of trial and error. There is very little risk in this method of procedure, and great prospect of success; but even allowing this, the builders on the northeast coast of England deserve very great credit for the general accuracy of the results obtained by them not merely in the matter of dead-weight carrying, but in the very important matter of trim. For the Clyde shipbuilders, however, the method of trial and error is not as a rule available. They have to deal with a vast variety of work, with results required by owners, which are frequently complex and often contradictory, and they have to produce from this basis workworthy of the name of the river. These conditions, it must be conceded, require methods of larger observation, more careful experiment, more thought, and more application of the results obtained. These methods are of first importance to the Clyde shipbuilders. There is no middle course open for such of them as are desirous of keeping abreast of the complexity of modern shipbuilding work, excepting that of going heartily in for scientific method, developing it as a portion of their business, and spending their money freely upon such development. Those who neglect to do this occupy a middle position, without either the advantages and the safety of the trial and error method or the advantages of the absolutely scientific and experimental method. Those who are resolved to adopt the increased trouble and the greater duties involved in this work, while they will find more labor in their work, will find more pleasure also in it; and I make an appeal to all Clyde builders to view this matter thoroughly and carefully, as it would have been viewed, were he present among us, by the man in whose honor I have had the pleasure of delivering this lecture.

APPENDIX.

TRIPLE EXPANSION ENGINES.

Since delivering the Watt lecture, I have had the following correspondence with Mr. Alexander Taylor, consulting engineer, Newcastle-on-Tyne, which, in fairness to all concerned, should, I think, be published. In connection with this subject, however, it is to be remarked that both in the *Propontis* and *Aberdeen* the plan employed by Mr. Kirk was not that patented by him, but an arrangement of three cylinders placed in the order of their size on the line of the shaft, and working upon three cranks, each cylinder having its own crank.

25 Queen Street, Newcastle-on-Tyne,
February 6, 1882.

Dear Sir: I trust that the well-known interest you take in all that concerns shipping may be considered sufficient excuse for troubling you with this and the inclosed copy of a letter I have sent to some of the Scotch newspapers; but whether the letter is published or not, I am anxious to place the matter before you.

I may further state that I expect to see the boiler for the *Claremont* s. s. tested in Kirkcaldy on Wednesday first, and as the engines are now on board, it would give me pleasure to show them to any of your people if you are interested in the matter.

I would also be glad to send for your perusal the letters I have received from the engineer of the yacht *Isa* since she left on her present commission.

An elaborate set of indicator diagrams were taken from the yacht *Isa* about two years since, when we had under consideration the adoption or rejection of a certain propeller. These cards were taken by Messrs. Palmer & Co.'s officials, and might interest you; if so, I will gladly forward some of them for your inspection.

Yours, truly,

A. TAYLOR.

William Denny, Esq., *Dumbarton.*

[Inclosure.]

25 Queen Street, Newcastle-on-Tyne,
February 6, 1882.

Sir: My attention has been called to the newspaper reports of Mr. W. Denny's lecture upon "The speed and carrying of screw steamers," delivered to the Greenock Philosophical Society on the 19th January last, wherein Mr. Denny states: "At the present moment there was proposed a method of diminishing the coal consumption required for a given development of power, and was being fitted by Mr. A. C. Kirk in the steamer Aberdeen. The principle involved was that known as triple expansion; that was, expansion through three cylinders successively."

Allow me through your columns to inform those of your readers who may be interested in the progress of marine engineering that in 1876 I designed an engine having three expansions in three cylinders upon two cranks, as recently patented by Mr. Kirk. This engine was built by Messrs Douglas & Grant, of Kirkcaldy, and fitted into the yacht *Isa*, in 1877, and illustrated in *Engineering*, of March 7, 1879, and is still doing splendid work in the *Isa*, at present in the Mediterranean, with the owner. The working pressure is 120 pounds per square inch.

My friends, Messrs Fisher, Renwick & Co., steamship owners, of this town, had the courage to allow me to specify the same style of engines for two of their cargo steamers, the *Claremont*, which was recently adrift on the North Sea while on her way to receive the machinery, being one of them. The working pressure is 150 pounds per square inch.

On the 5th December last, when I noticed Mr. Kirk had patented this type of engine, I placed the above facts before him, and he most handsomely wrote to me stating his ignorance of such, and that he would disclaim his patent right.

As far as I know, I was the first to put this style of engine into practical use.

Yours, truly,

A. TAYLOR.

Leven Ship-Yard, Dumbarton,
February 7, 1882.

Dear Sir: I am much obliged for your letter of yesterday and its inclosure, and the interesting information they contain, which is all the more interesting to us as we are just about to fit a triple expansion engine in a steam tender for ourselves, upon which we hope to carry out pretty exhaustive experiments and trials. The engine will be of the type fitted by you in the *Isa*. My partner, Mr. Brock, had such an engine designed before Mr. Kirk took out his patent, and, like yourself, informed him that he was not patenting an original idea. As far as I can learn, you seem to be the first to have introduced the tandem arrangement for triple expansion. As far as I can learn, however, Mr. Kirk deserves the credit for introducing the triple expansion principle, which he did in the *Propontis* in 1874, he having designed her engines at that time while acting as engine-works manager with Messrs John Elder & Co. Her cylinders were respectively 23″, 41″, and 62″ in diameter, with a stroke of 42″.

Thanking you for your letter, believe me, yours, truly,

WM. DENNY.

Alexander Taylor, Esq.,
25 Queen Street, Newcastle-on-Tyne.

25 Queen Street, Newcastle-on-Tyne,
February 9, 1882.

Dear Sir: I am extremely obliged for your very kind letter of the 7th instant.

Yours, truly,

A. TAYLOR.

William Denny, Esq., *Dumbarton.*

ON PROGRESSIVE TRIALS.

By J. Harvard Biles, Esq., *Member*.

[Read at the twenty-third session of the Institution of Naval Architects, 31st March, 1882; the Right Hon. the Earl of Ravensworth, president, in the chair.]

Progressive measured mile trials were first made by Mr. William Denny in 1875, and since that time it has been the general practice with Messrs. Denny, and several other Clyde firms, to have similar trials with every ship. It is my duty to carry out these trials for Messrs. James and George Thompson, and the results given are for ships built and engined by them. The supposed advantages to be gained are—

(1) A determination of the initial or statical engine friction, or that friction which is due to tightness of moving parts.

(2) A means of determining the horse-power necessary to drive ships of similar forms and proportions to those tried, but of different absolute dimensions.

The method of carrying out these trials on the Clyde is to make four or five sets of runs at different speeds, each set being composed of one run with the tide, and one against. The revolutions and I. H. P. on each run are determined, and the means of the two of each set are taken and set up on curves with speed for abscissæ and revolutions, I. H. P., &c., as ordinates. These trials take from three to six hours, according to the length and speed of the ship. The results of such trials are only approximately reliable where the tide is either very slow or very uniform, and would be quite unreliable where the tide is fast and variable, such as at Stokes Bay or the Maplin Sands. This is particularly true at the lower speeds, upon which depends the determination of the initial friction of the engine, for if the tide varies, say one-half a knot per hour between the beginning of the first and second runs of the set, the mean speed is in error one quarter of a knot. I propose, in this paper, to lay before the institution the description of some modifications in the method of carrying out these trials, which I submit for your consideration as improvements on the present system. The results of some trials made side by side with the ordinary system are also given.

The principle of the method I have been trying is to measure the time that a certain part of the length of the ship takes to pass an object thrown from the bows of the vessel, well clear of the side. From this observed time the speed of the ship may be deduced. The first difficulty is to measure this time with sufficient accuracy, for on a ship 400 feet long, moving at 15 knots per hour, the interval to measure is only about

12 seconds, and an error of one-fifth of a second produces an error of one-fourth of a knot. To measure this time accurately the instrument shown in Fig. 4 (Plate IX) was devised.

A is a cylinder driven by a clockwork motion; B is another cylinder free to revolve, on which a continuous roll of paper is fixed. The paper has its end passing over the cylinder A, and is drawn by it from the continuous roll at a uniform rate. C, D, E, and F are four pencil-pens which can each be moved sideways by a small electro-magnet, when an electric circuit in which the particular magnet happens to be, is closed. The magnet opposite the pen is connected to a well-made lever clock by short electric wires, so that every *stroke* of the lever causes the pen to move sideways. As the paper is moving continuously past the point of the pen the side motion causes a zigzag line to be made, the sharp points in which represent the commencement of each stroke of the lever. Hence, this pen records *time* on the paper.

Forward, at about one-fourth of the ship's length from the bow, two sights are placed exactly in a transverse plane; a similar set is also placed as far aft as possible. At each set of sights an observer is placed, and from him electric wires are led to the instrument and connected, so that when he makes contact the pens D and E, respectively, are made to move sideways. Hence, if a piece of wood be thrown from the bow, and the forward observer makes contact exactly at the instant that it passes his plane of sight, a break will be made in the line in which this pen is working. This break squared over on to the line which the pen C is marking will enable one to say, exactly, the time at which the piece of wood passed the forward sights. Similarly, the time at which the same piece passes the after observer may be determined, and the difference will give the time that the ship took to pass through the distance between the sights. The pen F is connected, electrically, to a contact maker, which is attached to the air-pump lever, so that this pen records, on the same paper, the revolutions of the engine.

G is a pendulum, of very short period, which records, continuously, the heel of the ship.

For many valuable suggestions in connection with the details of this instrument I am very much indebted to Mr. Froude, who uses time-recording instruments, of a very similar nature, in connection with his investigations at Torquay.

This instrument was devised with a view to obviating the necessity for making progressive measured mile trials, which are very tedious to any but those directly interested in the results. Many ship-builders do not care to spend the time necessary for these trials, but prefer to spend it with the engines going at full speed for a few hours, and also to take advantage of the time and opportunity to have a run out to sea with a party on board. If, therefore, some means could be devised which should fulfill both purposes, many more ship-builders might be disposed to have these progressive trials, and be benefited accordingly by the information obtained. The determination of the speed by the method described above, which may be called the "log method," fulfills this purpose, *provided that it is reliable*, for the ship might be run for a few minutes at each of several selected speeds, and the results obtained be put into the form of a curve, as in the ordinary method.

These several speeds could all be run in the one direction, for, as the marks which determine the speed are floating on the water, they are quite independent of the speed of the tide, and need not therefore be run one with and one against the tide.

In order to test the reliability of the method, trials have been made with several ships. The ordinary runs have been run on the measured mile at Skelmorlie, Firth of Clyde, &c., and at the same time the "log" results have been taken. The following table shows the comparison of the two in the case of the S. S. *Spartan:*

TABLE No. I.

No. of run.	Speed by measured mile, post method.	Mean of two runs.	Mean speed by log.
2	12.175	12.071	11.93
3	11.967		11.92
4	14.241	14.007	13.81
6	13.773		13.83
8	6.249	6.513	6.24
10	6.777		6.56
12	8.845	9.58	9.59
13	10.315		9.53

The results of the whole of the trials are given in Table No. II, Appendix.

In carrying out the analysis necessary to get these results, it was found that much information could be got by this method, which, from a scientific point of view, is of more value than the saving of time and prevention of *ennui* in a trial trip-pleasure party. It is worth considering what are the elements which tend to make the naked results somewhat in error. The first is the personal error of the observers, which must be allowed for when intervals as short as fifteen seconds have to be measured to a degree of accuracy of, say, one per cent.

The method of determining this is to let the two observers come to the forward sight, and together observe and signal through different electric wires the time at which wood thrown from the bow passes their plane of sight. The difference in the time at which they signal the same event is the "personal equation." The mean of the differences of time recorded by several observations was assumed to be the actual "personal equation," but this will probably vary during the run.

The second cause of error is due to the stream line disturbance which affects the position of the floating object relatively to undisturbed water. How much this error is it is difficult to say, but it seems probable that it is a constant percentage of the speed of the ship, for the floating object gets an average of all the waves made by the ship as she passes by it. If this is so the log will have what may be called a rate (similar to a chronometer), which may be applied to it as a correction. It will be shown later on that this assumption appears reasonable. If the wood be thrown at unequal distances from the ship's side the percentage or "rate" will probably vary.

A further cause of error of á similar nature is that due to the surface drift of the object caused by the wind, but this cannot be very great, especially at the high speed, for a piece of wood 6 inches square and 1 inch thick is not likely to be driven far in fifteen seconds. It is intended, however, when opportunity serves, to endeavor to determine this quantity for a given speed of wind. These are, as far as I can discover, the only probable causes of error in steamship trials which are peculiar to this method, but there is another cause of error which is common to all methods of carrying out trials whose existence cannot be detected by the ordinary system, but may be by the log method. It is the error due to acceleration or retardation of ship, caused by either an increase or decrease of steam pressure, or a passage from a tide of one speed to one of a greater or less speed. To show the necessity for taking notice of this in exact investigations, it may be observed that in the S. S. *Spartan*, from which the table was compiled, the total mean steam pressure in the engines did not exceed ninety tons, while a force of at least 9 tons, or 10 per cent. of the whole power of engines acting for four minutes (the time required to do a knot at the rate of fifteen knots per hour), would be necessary to accelerate the speed of a ship one-quarter of a knot an hour. Hence considerable errors may thus creep in. Mr. R. E. Froude has been good enough to give me the results of his investigations on this question, and he says that "roundly to get a given maximum percentage error from the supposed cause, the experiments must occupy the same given distance of run, whatever may be the speed." Acting on the suggestion, the ship was always brought into the straight opposite the same points on the shore.

Fig. 1 (Plate VI) shows the results in a graphic form. Along a base line the time of day is set off generally to a scale of 2 inches = 1 minute.* The speeds for each observation made is deduced and set up from the base on a scale of 1 inch = 1 knot, at a time corresponding to the middle of the observation. A freehand curve is drawn through the spots so obtained, and the mean speed determined by taking the arithmetic mean. The spots set off include some errors of observation, but a mean line run through these curves, as shown in No. 8 run, Fig. 1, will represent the curve of speed of the ship during that run. The spots marked thus ⊕ at each end of the diagram represent the speed over the ground

* In Plate VI the scale has been reduced.

at each end of the mile as measured, by noting the time the part of the length of the ship between the sights took to pass the mile posts. No. 8 run shows a very marked acceleration during the run, and consequently the mean speed over the run is not so high as run No. 10, though the mean revolutions are higher. The dotted curves overrunning the log results are revolutions of the engines deduced from the record made by the pen F, and to a scale suitable to make the two curves overlap. Representing them in this way renders it easy to see whether a gradual increase of speed is preceded or followed by an increase of revolutions. If it is preceded by an increase, it is probable that the change of speed is due to an increase of steam pressure; if it is followed by an increase of revolutions, it is probable that the ship has passed into a slower tide.

So far the work is straightforward and simple, and the results obtained correspond generally within about 1 per cent. of those obtained by the ordinary method. The only marked departure from this is in run No. 8, where there is a difference of 6 per cent., but the diagram shows that there was considerable acceleration, which probably accounts for the discrepancy. And at this point I should have been contented and compelled to leave the results, but on communicating them to Mr. Froude, he suggested further analysis, which has added considerably to the value of these observations. The first one suggested has reference to what has already been spoken of, viz, the "rate" of the log due to the stream line disturbance. The mathematical investigation on which it depends is given in the appendix, but the principle of it is quite simple. In two runs made at approximately the same speed through the water—one with and one against the tide—the difference of the speeds so obtained is a measure of the speed of the tide. The "log" gives a speed which it is assumed is a constant proportion of the true speed; it will only be necessary to know what this constant proportion or "rate" is in order to deduce the speed of the tide. If we assume a series of values for this "rate" and determine the tide speed, we may set these results off and form a curve. The tide curve will not be likely to have any abrupt changes in its character, so that tide curves deduced on certain assumed values of the "rate" which have a zigzag form may be thrown out, and the assumed value of the "rate" that gives the curve which appears most reasonable may be taken as the most probable value of the "rate." This investigation was made, and the "rate" which appeared the most probable was 1.013. The tide curve determined is shown in Fig. 2 (Plate VII), the dotted ones given being those which were obtained on other assumed values of the "rate," and which did not appear to be probable curves.

The whole of the "log" speeds were corrected for this "rate," and the speeds, as measured by the mile posts, were corrected for the actual speed of tide determined. The results correspond in a remarkable degree.

The second analysis is one which the limits of this paper will not admit of being given now, but which it is to be hoped may be given by Mr. Froude himself at another time.

The object of it is to put a correction on the revolutions by the log and to deduce the true revolutions which should have been made had the ship been moving free from acceleration and in tideless water. These corrections have been made for the results given, and are shown in Fig. 3 (Plate VIII). The curve marked A is the I. H. P., uncorrected for either log "rate" or revolution; (B) is corrected for log "rate" only; and (C) is corrected from (B) for revolutions. The curve marked (C) appears to be the most likely to be right. Resistance curves, as deduced by model experiments, generally show humps and hollows, as was shown by Mr. Froude in his very able paper last year; but the corresponding peculiarity does not develop itself in I. H. P. curves of ships frequently, as the speeds at which the ship is run are too few to detect them, and the speeds at which these humps and hollows exist is rather higher than that generally obtained by ordinary ships. If, however, they can be shown to exist in actual ships, it will greatly confirm the accuracy of the results predicted by model experiments. There is some considerable degree of probability that the humps shown on the I. H. P. curve are real.

My object in bringing these facts to your notice is to endeavor to get ship-builders and engineers to go into this question of steamship propulsion more fully and more accurately than has been done. If, by the results given, additional interest is raised in the question, my object will have been to some extent realized, for it is only by accurate trials that we can hope to get at the causes of such great loss of power as are known to exist in steamships.

APPENDIX.

If V_1, V_2, V_3, &c., are the speeds over the ground of runs 1, 2, 3, &c., and v_1, v_2, v_3, &c., those apparent speeds through the water as given by the "log," then, supposing the first run is against the tide—

Tide during run 1.... $t_1 = kv_1 - V_1$,
2.... $t_2 = V_2 - kv_2$,
3.... $t_3 = kv_3 - V_3$,
&c., &c.,

k being *presumably* constant (but perhaps slightly variable with speed). Plot each of the above equations as a diagram of tide in terms of k, substituting the observed values of v_1, v_2, v_3, &c., and V_1, V_2, V_3, &c. This is done for the S. S. *Spartan's* results in Fig. 2 (Plate VIII).

If the rate be assumed to be 1.03, and the points where the ordinate at this value of k cuts the different straight lines drawn representing the variation of tide and rate be measured from the base, and set up with time of day as abscissæ, a tide curve may be drawn through these spots. The curve AA deduced for the assumed rate is unreasonable, being of a zigzag form, but by trying several values of k a fair curve may generally be found, as BB.

If a fair curve cannot be found, it will show that either the "rate" is not constant or that the data are inaccurate.

TABLE No. II.

No. of run.	Time of day.	With or against tide.	Steam at E. Room gauge.	Vacuum.	Revolutions. Mean of run.	Revolutions. Corrected by Mr. Froude's method.	Speed by mile posts.	Speed by log.	Speed by mile post corrected for tide.	Speed by log, corrected for log "rate."	Slip per cent. as ordin. taken.	Slip per cent. by corrected revolutions and corrected speed.	I. H. P. uncorrected.	Mean effect pressure.	I. H. P. corrected.
1	10. 49 to 10. 54	Against	64	28	51. 3	51. 8	....	11. 77	....	11. 946	7. 446	8. 31	1, 578. 4	16. 812	1, 593. 7
2	11. 20 to 11. 27	With	72	28½	51. 91	52. 45	12. 175	11. 93	12. 115	12. 109	7. 243	8. 191 by posts; 8. 237 by log.	1, 635. 6	17. 291	1, 652. 7
3	11. 49 to 11. 55	Against	74	28	52. 4	53. 3	11. 967	11. 92	12. 107	12. 099	8. 169	9. 71 by posts; 9. 77 by log.	1, 646. 4	17. 238	1, 674. 6
4	12. 27 to 12. 32	With	67	26½	61. 55	62. 0	14. 241	13. 81	14. 021	14. 011	9. 46	10. 11 by posts; 11. 80 by log.	2, 904. 5	25. 132	2, 925. 5
5	12. 32 to 12. 38	With	69	27½	55. 85	54. 9	Not on mile	18. 23	....	13. 428	4. 441	2. 986	2, 192	21. 541	2, 154. 6
6	12. 59 to 1. 5	Against	70	27	61. 42	61. 0	13. 764	13. 83	14. 034	14. 032	9. 183	8. 569 by posts; 8. 503 by log.	2, 923. 5	26. 121	2, 903. 5
7	1. 10 to 1. 14	Against	69	27½	53. 81		Not on mile	12. 82	....	13. 012	3. 992	3. 992	1, 868. 9	19. 113	....
8	1. 34 to 1. 46	With	72 at begin. 69 at end...	26 24	25. 92	26. 375	6. 249	6. 24	6. 029	6. 334	7. 545	9.146 by posts; 4. 549 by log.	278. 4 372. 8	5. 895 7. 032	331. 3
9	1. 50 to 1. 58	With.	62	28	47. 16	46. 6	Not on mile.	11. 03	....	11. 195	5. 647	4. 511	1, 275. 1	14, 804	1, 259. 9
10	2. 19 to 2. 29	High water	61 at begin 60 at end...	26 26	24. 62	25. 75	6. 777	6. 56	6. 677	6. 658	—7. 451	—3. 075	215 300	Beg. 4. 902 End 4. 539	269. 2
				28½	40. 5	40. 7	Not on mile.	9 368	....	9. 592	5. 86	6. 326	762. 9	10. 335	766. 6
11	2. 35 to 2. 40	With	58	28½	39. 9	39. 0	8. 845	9. 59	9 725	9. 734	3. 128	0. 89 by posts; 1. 250 by log.	768. 2	10. 544	750. 8
12	3. 0 to 3. 10	Against	58												
13	3. 35 to 3. 41	With	58	28½	40. 3	39. 5	10. 315	9. 53	9. 715	9. 673	4. 191	1. 67	763. 4	10. 395	748. 2

DISCUSSION.

Sir E. J. Reed. My lord, I have nothing very particular to say about this paper, except that it seems to me to be a very interesting one, and one presenting a most interesting aspect to me, as it involves a sort of analysis of what happens to a ship on the ordinary measured mile. I have often wondered to myself to what extent a ship came on the mile with proper revolutions, proper power, and doing everything at her best, and to what extent she did not. This paper and the curve, which Mr. Biles points out, give us a most interesting analysis of that. There is one practical point which has not been mentioned or explained which I should like to hear a word or two upon from Mr. Biles, and that is, how an observer, with these transit marks, is able to pick up the view of a little piece of wood, six inches square and one inch thick, thrown over by the bow, with the ship going at a high speed, with sufficient definiteness, promptness, and clearness, to make sure of his transit observation. I do not for a moment suggest that it cannot be done, because the results of the observations appear to show that it is done, and done with great nicety. The correspondence, as Mr. Biles has said, between the results of speeds as observed by the two different methods, is remarkable; the discrepancies between the two are very slight indeed, except in one case, which he explained. I should like Mr. Biles, in his reply, to say how in practice it happens that two observers can pick up the sight of such a small piece of wood floating past, with sufficient certainty to be able to observe it, and enable them to ascertain its transit past two different points of the ship, with undoubted accuracy. I should like to say that I think this paper opens up a line of investigation which will prove very interesting, and which, in its development, will throw a good deal of light indeed on the performances of steamships.

Mr. J. D'Aguilar Samuda. My lord, I quite agree with Sir Edward Reed that the ingenuity of the arrangement and the objects sought to be effected are most valuable, but it would occur to me to recommend Mr. Biles to apply the ingenuity which has here been given to us to the mode of carrying out the ordinary trials of steamships by the measured mile; and for this reason. It appears to me that the whole value of measured mile trials is the accuracy you can obtain, and the whole deviations which must result from the application of this mode of measuring must go a great deal away from accuracy compared to that which we get on the measured mile trials; it is impossible for it to be otherwise. You have here to measure an immensely reduced distance to begin with. Then you have to obtain your formula, by taking observations, first under the difficult circumstances which were so well explained by Sir Edward Reed—you have not only to look at posts, but you have to bring those posts into your observations, in conjunction with a floating surface of a small description, which is very difficult—and then, more difficult still than the whole of these observations to get accuracy, is that you have got to take the observations of different observers. It is marvellous, with practice, how they will agree when you come to look at the measured mile. Observers will come to an equally correct result, although one man actually notices it a quarter or half a second after another; but he does it continuously, in coming on to the line and off the line with his watch in his hand. He takes the observation in a particular way and records it in one way, and another observer has to take it at the end of the time and record it in another way. Then the mixing up of these two observations must be a source of error and a source of deviation, which one does not fall into when all of it can be done by one person. That is a necessary consequence. Then I think myself, another great source of error which cannot be estimated correctly, but which, I think, with the greatest possible care, must more or less be taken into account, is this: a vessel passing at any considerable rate through the water must have a very considerable influence on the water for a considerable distance beyond it, and with regard to throwing overboard anything in the way you have here described, it would be more correct or less correct, according as you threw the piece of wood or float a greater or a less distance away from the ship.

Sir E. J. Reed. He mentions that.

Mr. Samuda. Yes, he mentions that, but he admits it is a difficult thing, and I think so difficult that it would in practice interfere materially with the correctness of his observations. Another matter which again appears to me to be very difficult is this. I am speaking, not in any shape or way, in derogation of the ingenuity of the arrangement he has made—because I consider that the application of this to ordinary mile trials would be an improvement—but I am speaking as to the substitution of this mode of measuring speeds as being at all comparable with the old existing mode of measuring speeds. The other mode is this. He proposes to get a measured mile. You are passing over one movement in one direction only, and one movement in the other direction only; but the one movement in the one direction does not give you the result of the passage of a ship. It is absolutely necessary that you should pass several times over it, and that you should get the mean of those passages if the tide during the time that you are passing is either accelerating or diminishing, and it always is either accelerating or diminishing. Therefore you have another source of security in the present mode of measuring the mile, which you fail to have in this. Therefore, taking it altogether, though I think it is extremely ingenious, and though as I think in the progress of six mile trials there and back you may get very excellent approximate results by this, you cannot accept it as being an improvement on the way already in use for our best mile trials. I think we must thank Mr. Biles for having brought the matter before us, but we must recommend him to apply his ingenuity to bringing us next time, or whenever the opportunity may serve him, the result which he can get by applying this to the entire mile trials, instead of to the length of the ship only. Again, the source of error is enormously increased by having to make your observations of these various observers over so small a distance as 400 feet, instead of a distance of 6,000 feet. Therefore, I think it will be altogether rather rash to rely on this as an improvement upon the existing method.

Mr. JOHN SCOTT. My lord, I think it is due to the author of this paper, Mr. Biles, to express the great satisfaction that the reading of it, or rather the hearing of it, has given me. I think that a great deal of credit is due to the author of this system for having in a scientific manner utilized a very ancient method of taking the speeds of ships. I fancy that the method of throwing a log overboard is positively the very oldest method by which ancient navigators endeavored to ascertain the speed at which their vessels were passing through the water. That brings to my recollection rather a remarkable trial at which I was present, and in which I had the honor of being assisted by two of possibly the most eminent members of this Institution, who have now passed away from us—my old friends, the late Professor Macquorn Rankine and Mr. James R. Napier. I recollect being present with them at the trial of what was then a rather remarkable steamer, the *Thetis*, which was fitted with the first compound engines carrying a high pressure of steam that ever went to sea. We were not then in possession of a measured mile on the Clyde, on which accurate trials could be made, and from the state of the weather it was impossible to use our long measured distance. I think it was Professor Rankine suggested that we should throw logs overboard, and endeavor to ascertain what the speed of that ship was relatively to the power, so as to avoid loss of time. Professor Rankine observed the time at one end of the ship, and Mr. James R. Napier at the other. They had not the advantage of the elegant instrument which has been brought before us by Mr. Biles, and they were obliged to signal the time from one to the other; but still a very good rough approximation, even in that way, was obtained on that occasion. It is impossible, as has been remarked by some of the speakers to-day, with reference to such a technical paper as this, to express an opinion right off as to the value of the curves and the various statements laid before us. But it appears to me that those curves which are shown on Fig. 1 (Plate VI) indicate rather a remarkable feature which is well worthy of notice. I think when one observes the revolutions of the engines which virtually express the power that is being developed at the moment, in reference to the line which indicates revolutions—relatively to the line which indicates the speed, there is very strong evidence of the fact that in those shorter intervals, which are named at the bottom of the paper, one can trace about the influence way has on the ship; because it strikes me while the ship's speed shows a considerable variation the revolution curve does not. I do not know whether I observed it correctly or not, but I think that possibly that might be due to the system of showing the speed. There is one point I would like an explanation upon, and it is this: I would like to know whether this system has ever been tested on any measured mile where the speed of current is very great. It was tried on the measured mile at Skelmorlie where the influence of the current was very small; but I should like to know the result of a trial made where there might be possibly a greater lower surface current than upper surface current, because I think that would have a very important bearing on the accuracy of this system. I think deep draught vessels might be subject to a very strong under current, while vessels of lighter draught might be subject to a more or less strong surface current. I think that point might be taken into consideration advantageously by the author of this paper.

Mr. William Denny. My lord, my name has been mentioned in this paper, and therefore, although I have spoken frequently at these meetings, I feel compelled to speak in this case. It is not often that anyone who has introduced a novelty such as I have had the pleasure of doing in progressive speed trials, can say, heartily and honestly, that he is glad to be superseded, or to see the probability of being superseded. I assure you that I can say this, because my anxiety is so great to get measured mile trials conducted with accuracy and frequency of observation, so as to render them comparable with model trials, that I would sooner see constant progress than any special advantage or reputation to myself. I think we should not forget that the writer of this paper, while he is a Clyde man by habitation, is a royal naval collegeman by education; and this is another illustration of the advantages we owe to that establishment of the Government, advantages for which we, as an institution, may claim credit on account of our efforts in promoting it. Mr. Biles has remarked that this method has a practical value because it enables a trial to be conducted along with what may be called a pleasure trip. Anybody who has had to do with trial trips must know that this is often a necessity. But there are other practical reasons why this method of trial is advantageous, although less advantageous to the Clyde than to other places. We on the Clyde are favored with a nearly tideless measured mile, on which you can easily observe the posts, and we are situated very advantageously on this account. I cannot speak fully on some of the points raised by Mr. Biles, because I have only once or twice had the opportunity of talking of them with him. But, by means of this method, I hope ultimately all the trial waters of the country may be put upon an equality. When I look round and see one of my friends from the East Coast sitting here, I may congratulate him and say, here is a method that will put in his power, and in the power of East Coast builders generally, the means of accurate observations of speed, and enable them to produce as accurate work in this respect as they produce in dead-weight capacity. To speak now of Mr. Samuda's idea of keeping these trials running alongside of the measured mile trials, I think that for some time to come, at any rate, the two should be carried out together, so as to check these more refined trials. I would ask Mr. Biles a question with regard to the circular marks denoting the speed at the beginning and the end of the run. I do not exactly understand how they are obtained, because, as every one in this institution is aware, the observation of speed, during a measured mile, is the mean of the speeds obtained throughout that measured mile, and I do not see how he obtains exactly the measured speed at the commencement of the measured mile and at the end of it. The interval, I see, is from 20 minutes past 1 to 45 minutes past 1, which I should fancy is the time required to pass the mile at the speed. Now, my lord, perhaps one of the most important points Mr. Biles has raised is as to the necessity of finding out the position of the humps in speed diagrams from the indicated horse-power trials. We all know that these humps occur at the higher speeds, and that when it comes to the question of dealing with very high-speed express steamers for the Atlantic trade, we are very quickly confronted with a problem which has not yet come up with even such a steamer as the *Stirling Castle*, which your lordship referred to in terms of high praise. We all know from Mr. Froude's able experiments, and those of his father, that so long as you are on the slack before the hump you can go on increasing the power and applying it to the given type of vessel with great advantage. But there comes a time, when you get on the face of the hump, when to continue to apply power is simple folly. This will need to be looked out for very carefully in the future consideration of the question of high-speed vessels. I think many of those gentlemen who have spoken on the subject have not sufficiently considered this. You can go on with a given sized vessel until you come to the front of the hump, and then you may be compelled to drop that size of vessel and the application of power to her, and go to a larger vessel. This question of express steamers is surrounded by a hedge of thorns, and requires to be elaborated by scientific method and experiment. Mr. Samuda has made some remarks on the relative value of measured mile trials, and Mr. Biles's method; but I think in these remarks Mr. Samuda has failed to see that there are two sides to the question—that while the trial at long distances gives accuracy of observation for speed, it does not give accuracy of observation for revolutions and power. So much has this been the case, that the history of trials of steamers has been as follows: First of all, we had trials of steamers at sea for many hours; but we know that the trials were inaccurate, because you could not be sure of getting the revolutions and indicated horse-power correctly. Then we came to trials of 16 or 13 miles, but we had to give up those also, because we could not get a perfectly accurate observation of the power and the revolutions. Then we came to measured-mile trials, where we took the revolutions throughout the run by reading a counter at the beginning and at the end, but not in the excellent way Mr. Biles has done. Now, if we are to go on improving, we must come to something very much closer. As far as I can understand, for each of these observations which Mr. Biles makes there is an immediate communication with the engine-room, and a diagram is taken instantaneously. The refinement of this method is of immense advantage, because by its means you get one side of the experiment right. Of course I agree with Mr. Samuda so far that we ought to be very careful that we get the speed element correct. But do not forget that there are two elements involved. There is yet another point. Mr. Biles's method, if it comes out as I hope it will come out, is a method promising us not only accuracy, but frequency of observation. I hear Sir Edward Reed approving of this, and I know that he approves of it from full experience. He must know as well as I do that even in our best progressive trials where we have five mean speeds on the curve, we often say, Why could we not have ten? There are points on the curve which want illustration and development, and we cannot get them illustrated. This method promises the necessary information. Therefore I think while we ought to criticise Mr. Biles—and I am sure he invites criticism—at the same time we ought to welcome this thing, as perhaps the most promising test of speed ever offered to this institution.

Mr. P. Jenkins. My lord, having had some few years ago experience of measured mile trials, I should like to offer a few remarks on the paper of Mr. Biles. Five years ago some experiments were undertaken at Portland on board the *Thunderer*, with a view to ascertaining the amount of her inclination to the vertical when moving in a circle at definite speeds. On that occasion we flung overboard empty champagne bottles to ascertain the speed of the vessel, and recorded the times at which they passed fixed sights placed at certain intervals on board. We simply recorded the times with common watches, and when the results came to be plotted we found that they did not give anything like such accurate results as we could have wished; in fact, the speed of the vessel could not be well estimated within something like a knot. That was due to two causes: First, the personal error of the gentlemen who were taking the record of time; and, in the second place, we had no apparatus from which we could read the time accurately. In that way those results, so far as speed was concerned, were not of much value. Now, with respect to personal error, I think much of it can be avoided by the operators exchanging places from time to time. The one at the bow might go to the stern, and the one at the stern might go to the bow, and in that way personal error could be minimized. But this point assumes much importance, I think, when the speed of the vessel is high. At low speeds I believe that the personal error will not greatly affect the result, but when the vessel occupies only a few seconds in passing a float, then personal error becomes of some considerable importance. I think the main value of these experiments is due to the fact that they will enable the speed of a vessel to be determined at low speeds with far greater accuracy than on the measured mile, and while, no doubt, they form admirable checks on the results over the mile at high speeds, they are not so good relatively as they are at low speeds. Then there is another point, viz, with regard to acceleration. When passing from one speed to another, the vessel takes some time, even after the revolutions have been altered, to reduce her speed to that desired, and if great care is not taken in going on the mile or when this method is introduced, you are liable and likely to mix up the speed the vessel had previously with the new speeed. It was found in some experiments with the *Iris* that it was very necessary that the ship should steam away to some distance beyond the measured mile-post before she turned again and came on to the mile, so that she might get up the speed required. I see that Mr. Biles has here made so many records that that kind of thing would be obviated, but in the hands of some people it might happen that to economize time only four, five, or six observations will be taken, and then I think most important errors might be introduced. When analyzing the measured-mile trials of the *Iris*, we constructed, with the aid of the revolutions per minute of the engines, in a manner very similar apparently to that adopted by Mr. Biles, a series of lines, which represented, as those do, the speed of the ship, with certain definite values of K. We found that K was a variable element. It changed in value, as the number of revolutions per minute changed, and we constructed a tide curve K, being varied so as to make the tide curve fair. We introduced another refinement into that method of calculation, which I do not think Mr. Biles has done, and which I would recommend to his notice; that is, that when we had settled on those values of the coefficient K (which gave a fair time curve), we set about constructing a revolution curve in terms of K as well. You ought to get a fair revolution curve in conjunction with a fair tide curve for variations in the value of K. Then I think we were not wrong in assuming that we had as correct, or as nearly correct, a tide curve as it was possible to get under the circumstances.

Mr. Hall. My lord, I shall be glad to add a word of praise on this paper, because it is upon a subject which I have felt very great interest in from the commencement. I was present at the trial of the instrument on board the *Thames*, and was very much pleased indeed with its working. I had not the pleasure of hearing the previous part of the discussion which has taken place, but if I have not been anticipated by any other speaker, I would point out that there is an additional element of value in this instrument, which, perhaps, would not be looked for at first sight. In addition to obtaining a record of speed and power, as we do at present, of ships on trial trips at the measured mile, it enables you to make trials at sea, at the sea-going draught and trim, with all the usual sea-going circumstances. I apprehend that if we can get speed curves under these circumstances they will be of far more value to us, and more likely to be of service, than the curves obtained on the measured mile, with light trim and everything in your favor, as has been the case hitherto. I have felt so much interest in this subject that I got the instrnment admitted into the Electrical Exhibition at the Palace; it was rather late, but I shall be very much surprised if Mr. Biles does not get a medal for it. I think he amply deserves it.

Mr. PURVIS. My lord, I was present at the trial of the *Thames*, to which Mr. Hall has just referred; and I can testify to the great care and discipline with which the work in connection with this arrangement was carried out on that occasion; indeed, the care that was required, and the discipline that had undoubtedly been necessary, to bring the arrangements to the perfection with which they were working, seem to me to be two things against such extensive use of the method, as Mr. Biles advocates in this paper. If people hesitate to go into measured mile trials on account of the trouble, they will scarcely go in for the extra trouble that such a method as this would involve. Whether that is so or not, this method has, I think with Mr. Biles, a most important bearing upon the scientific points that can be brought out in measured mile trials. These things we have here in relation to the trials of the *Spartan* would not have been known had it not been for this or some similar method. For instance, in Run No. 10 (Plate VI) there seems to be from end to end a retardation of something nearly equal to 2 knots, and to deal with the mean of the results in such a case as that vitiates those results entirely. If the measured mile trial results are to be depended upon, the speed over the whole mile must be uniform, and must not have the variation that we see here. In the case of one of Messrs. Denny's ships, only last week, curious results occurred, which, if we had had such a method as this in use, might have been explained. A ship going down against the tide made a speed of 14 knots. The speed was kept up, and the ship was got round again, and came up with the tide with a speed of only 13½ knots. We cannot explain that, because we have not the means of so doing.

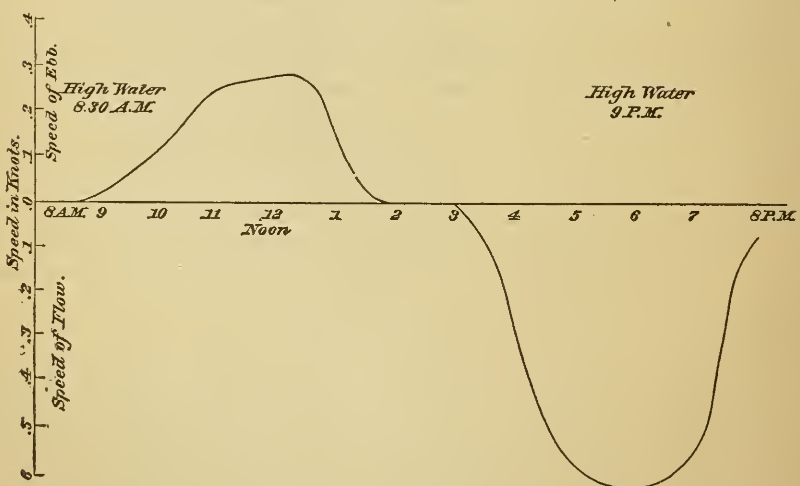
Mr. DENNY. She went down with the tide?

Mr. PURVIS. Against the tide, and returned with the tide at the rate of about half a knot less. The same ship was some hours afterwards put upon full speed trial again, and went down with the tide—then a small ebb tide—at the rate of 15 knots. She was not brought up against the tide, because some fault occurred in the pumping arrangement, and she was not able to keep her boiler properly supplied with water. I think what Mr. Biles says here shows the importance and value of such an apparatus as this. The particular way in which Mr. Biles logs the speed is extremely interesting, and Mr. Biles is to be congratulated on having, while other people have been talking about it, led the way and shown what can be done. I hope some better method of logging will be attained, and I hope the possibilities attaching to this instrument will yet come to the front, and that it will be a method of logging speeds, which, perhaps, some day we shall see brought to perfection.

Mr. Biles says that one of the advantages to be gained by measured mile trial is a determination of the initial friction. Having said that, he does not say much more about it. I had some talk with him on the subject before the paper was brought on, and I know that he at that time was going to refer to the difficulties at present in the way of estimating the initial friction, owing to the anomalies attaching to low-speed runs. We have found such a thing as this: that in cases where going down, whether with tide or against does not much matter, with twenty revolutions, you get a horse-power of 140; coming up again, with perhaps nineteen revolutions, you get an indicated horse-power of 50 per cent. more, or say 210. Such a thing as that is quite impossible to be explained, except by perhaps some accelerated effects which would be detected by Mr. Biles's method. At present such a result presents an anomaly that requires further investigation before the low speeds can be used in the way in which at present we attempt to use them, for determining accurately the initial friction of the engines. Now, with regard to the personal equation, Sir Edward Reed asked Mr. Biles a question upon that matter, and Mr. Samuda also referred to it.

CURVE OF SPEED OF TIDE AT SKELMORLIE.

[From observations made 19th September, 1881, four days before new moon.]



I should like to ask Mr. Biles myself, if he can tell us the absolute amount of the personal equation between the two observers and the variations between them. I think it is important, seeing that he tells us that at high speed a fifth of a second is equal to a quarter of a knot. One word with regard to the action of the tide, which I have obtained from the result of trials. One beautiful day last September I was staying at Skelmorlie with a family, one member of whom is on our staff. There were five of us together from eight o'clock in the morning until eight o'clock at night investigating the ebb and flow of the tide at that point, and we got very different curves—decidedly different curves—from those which Mr. Biles shows in Fig. 2 (Plate VII). We started with a slack tide in the morning, then an ebb tide up to midday, and then after that a flood tide. Ordinates like those in the figure above represent the speed of the tide at high tide. At low water here, for nearly two hours, or at any rate, there was nearly no tide at all; so that Mr. Biles's curve, according to our investigation, should rather come down, as shown in the figure above, then along the base, and then up. I mention that, because I think investigations of that sort should be gone into, as they have a distinct bearing upon the question of measured mile trials.

Mr. W. H. White. My lord, as a matter simply of history, perhaps I should say that this is our old friend the Dutchman's log come up again. We have had it referred to Professor Rankine, and probably it was in his mind an original suggestion; but I believe, as a matter of fact, it was used by Dutchmen in estimating the speed of their sailing ships, and it is called the Dutchman's log. Then with regard to the question of improvements in log, I hope that we shall have shortly something very satisfactory to report. For my own part, I have lost all faith in the possibility of getting good results out of any modification of the Berthon log attached to ships. I think we have in hand for the Admiralty what will be a success. It was begun in connection with the late Mr. Froude's advice, and is being worked upon now by Mr. Brunel. It is a screw log with electrical indications. It will be towed astern of the ship, and its indications will be permanently on board. There are many questions as to these log measurements which require the most careful consideration, combined with the greatest care. As one illustration, I may mention that the distance at which the log is towed astern of a ship, at different speeds, will affect the indication, and what is necessary is to determine the rate of the log, just as Mr. Biles has attempted to do. I merely mention these facts as the question of trials at sea has been mentioned. I quite indorse all that has been said as to the great value of this paper—I mean the practical value of it. I think if this kind of apparatus were used in connection with measured mile trials, Mr. Samuda is quite right in saying we should be free from a great many of the possible sources of error. I do not think that at very high speeds this could be substituted for a longer distance; but then, if we get a great number of observations, as Mr. Biles has shown, we get the means, as it were, of striking an average, which must not be forgotten as a set-off on the other side. It is not a flash past a post—a single observation. I have seen a number of observers, standing all about to take the time when they went off the mile, and certainly the observers did not agree—they very much disagreed, and it is necessary in all questions of fulfillment of contract where it is "touch and go" to have somebody whose "personal equation" is supposed to be known and believed in, and his voice must be final. I have known cases where the conditions of the contract were rather difficult, and the personal equation in other ways besides that unavoidable in making the observation had to be considered. I believe, as far as I have gone, in accurate automatic apparatus for observations of this kind. If the clock works well, and the electrical currents keep going, there can be no stories told. They are there on record permanently. It is not a question of what time you started with or what you ended at, but there it is—the thing is on record, and could be produced if necessary in a court of law, though I do not know if they would understand it. As to the trials of the *Iris*, referred to by Mr. Jenkins, and the conduct of the observations on board, Mr. Jenkins lent very material help. The *Iris* was a special vessel. Mr. Froude's staff came up from Chelston Cross in order to supplement the observations, which were ordinarily made with other and more scientific observations; and I hope some time or other they may be published. But this was the effect, as Mr. Jenkins pointed out—that in that high-speed finely-formed vessel with comparatively small resistance, if we did not take a big sweep off the mile, the vessel did not come on to the mile with anything like her speed. I know a case where an iron-clad with nearly 10,000 tons displacement was tried on two different occasions with nearly the same power. She was a vessel that could be turned round sharp—in about two minutes. When she was brought round very sharp on one trial there was a very sensible loss of speed; but on the second trial, with the same indicated horse-power, there was an increase of a knot in the speed over the first trial, although there was greater displacement on the second trial than there had been originally. The late Mr. Froude went into this matter very carefully in connection with some trials of ships of the *Encounter* class some years ago, and brought out this curious fact: that if the resistance actually varied, as the square of the speed, the ship would never get up to uniform speed, however long you kept her at it. It is in practice of the greatest importance to be quite sure that you are running pretty steady before you make speed observations. A point of the greatest value among the many points of interest and value in this paper is this. We are going on to greater and greater speeds, and we want to get those speeds as economically as we can; we have reason to believe that in model experiments, properly conducted, we can ascertain resistance. Now, we want to connect the effective horse-power with the indicated horse-power; and how is that to be done? It may be assisted by experiments with model screws, but it can only be resolved finally by the most accurate and careful comparison under similar conditions of speed trials of ships with speed trials of models. Now, Mr. Biles has shown us here (and I wish he had completed the column, showing the loss due to want of uniform motion—that is, the effect of retardation or acceleration on those curves), that it is impossible to take the ordinary mode of construction for speed and power curves and put it alongside a model experiment as an exactly accurate comparison. Unless that can be done, we must have a certain percentage of error—perhaps not a large one, but still an increasing one. To illustrate what I mean, it will be remembered that the late Mr. Froude, in the paper he read here on the *Merkara* trials, was then of opinion that the effective horse-power was usually about 37 per cent. of the indicated horse-power.

Mr. PURVIS. Forty-two, I think, is what Mr. Froude gives for the *Merkara.*

Mr. WHITE. Speaking of the fair average value, Mr. Froude said that about two and a half times the indicated horse-power was the fair value. I think he put the average ratio of efficient to indicated horse-power as 37. I know of cases where the same method of investigation applied by the Chelston Cross establishment has shown a ratio of effective to indicated horse-power of 55 per cent.—that is, that the effective has been 55 per cent. of the indicated. It shows what importance must be attached practically as well as scientifically to the accurate rendering of the facts of these measured mile trials. There is one point which I do not attach the importance to that Mr. Denny has attached to it, and that is with regard to the importance of these humps in the curves, except scientifically. It is quite true I agree with everything he said as to the desirability of selecting a form well adapted for the highest intended speed, but there are cases, such as torpedo-boats, in which the hump is surmounted, and the vessel goes much beyond that hump, and gets into much more favorable conditions.

Mr. W. DENNY. Will you allow me one moment to explain? I did not refer to the hump in that curve; I referred to the hump known to occur in almost every model trial. There was no hump in the *Merkara;* I did not refer to those humps.

Mr. WHITE. The hump to which Mr. Denny refers is the first hump in the series to which I am referring, and all that I said I still will allow to stand, if you will permit me. I say that, taking in all the conditions of ship construction, it may be desirable, although the hump does occur, to accept the hump in reaching the higher speed. There is no general law to be laid down, that is all I mean, and while I agree in principle with what Mr. Denny has said, I do not agree in his mode of applying it.

Mr. JORDAN. My lord, there is no doubt that in the paper Mr. Biles has read, we have a most interesting method of ascertaining the speed of ships. I agree with what Mr. White said just now, that the more we can rely upon self-acting mechanical apparatus in such things as these the more correct will be the results; and I would suggest to Mr. Biles the advisability of making some little spring gun concern to fire the float, which I think could be done in a similar way to the firing of torpedoes. You could then connect it with an electrical arrangement in such a way as to signal to your observer at the stern of the vessel the very moment that you fired the float, and you would have the advantage of being able to fire the float at right angles to the keel of the ship, which is very important, and at the same time get it recorded on the instrument. The whole thing could then be done by just the touch of a button.

Mr. Withy. My lord, I should like to ask Mr. Biles a question, but I will preface it by the remark that on the East Coast, where we more largely have cargo-carrying steamers, we have not gone in for anything of this kind. Some of us fully appreciate the advantages gained by those enterprising firms who take up such matters at considerable expense, and considerable loss of time, in some cases. The question I would like to ask Mr. Biles is, whether he thinks that progressive speed trials like this would be useful in ships from which no great speed is expected, but in which it is a matter of great importance to the owner to know at what speeds they can drive the ships most economically. The humps Mr. Denny mentions, I do not know that I quite understand; but, bearing in mind the very broad shoulders that many of our ships have, if they had, so to speak, a hump to push against at any point of their speed curves, it would be very desirable that we should know by progressive speed trials where the humps come, because to push against them might be a very hopeless thing. Therefore it would be very interesting to know whether it is possible to surmount these humps and figuratively run down the hill on the other side, and so get some further advantage. That may seem a funny proposition, but I am earnest in asking for information whether in slow cargo steamers we may yet find some advantages by going into this kind of thing. We have been apt to say that with slow speeds it does not matter very much having accurate trials, but this method seems to offer on one side perhaps a rather rough and ready method, seeing that there is the personal element in it, but on the other side a most accurate means of registering. I think one might steam about in the North Sea on a tolerably smooth day and carry on a number of these trials, because we might throw pieces of wood over *ad libitum*, and run for hours recording automatically on paper what we had been doing.

Mr. W. W. Rundell. My lord, Mr. Scott alluded to an interesting occasion on which the principal actors were Professor Rankine and Mr. Napier. I wish also to bring to your notice a reminiscence of a somewhat similar case, in which the principals were Mr. Froude and Mr. Scott Russell, wherein this Dutchman's log was used, and was, in fact, the only distinctly correct mode which could then be tried. This was in a very large vessel, and consequently her length eliminated some of the errors belonging to the method. I allude to the first trial of the *Great Eastern*. She, as we know, was between 600 and 700 feet in length, and consequently there was good scope for an experiment of this kind. Considerable care was taken to throw the floats, as Sir Edward Reed terms them, directly at right angles to the middle line of the ship, because no matter at what interval they reached the water, the correctness of the system depended on their being thrown out at right angles to the length of the ship, and the exact moment being indicated. I remember with some interest seeing those gentlemen perform their trial with a great deal of care and a great deal of skill. One object I had in rising was to refer to the No. 10 run (Fig. I, Plate VI.) upon the diagram, as showing the speed decreasing from seven to six knots. Here we have several specimens of "humps," and I fancy rather interesting ones. We have four of them occurring in the space of eight minutes, and the intervals of them seem to be very regular—we may allot about two minutes to each of them. Two modes of accounting for them have already been suggested I believe. One has been referred to by Mr. White, and the other by some other speaker. Of these two the one which attributes the "humps" to variations in the pressure of steam in the boiler does not seem to me so probable as that which refers them to a difference in the immersion of the screw. Here there seems to be a real cause of retardation and acceleration. The stern wave passing the screw it works in the trough gradually; being relieved, the wave rises and increases again, and so going on for four times during the eight minutes. I would like to ask Mr. Biles whether he has formed any opinion as to the cause of the regularity—the marked regularity—of the "humps" that are seen in that particular curve?

Mr. J. H. Biles. My lord, I feel exceedingly flattered at the very favorable reception which this paper has met with, far more than anything I could have anticipated. I may say that the whole question divides itself into two points—the scientific value of the paper which turned up, I may say, almost incidentally, and the practical value of it. The practical value of it is that it enables you to carry out in the same time a much larger number of trials, and to carry out sufficient number of trials or the same number which are generally carried out, in a much shorter time. The scientific value of the question is that it gives us, as Sir Edward Reed has said, a correct account of what the ship is doing during the whole of the mile. Those two things, I think, should be kept separately in view in this question. Sir Edward Reed asked whether there was any difficulty in observing the wood floats. I think there is none. I have often stood at the sides and have not found the slightest difficulty in seeing them, and when they were not seen they were not recorded, so that there was no cause of error on that account. Further than that, what I think will cover a good many of the objections raised by Mr. Samuda and Sir Edward Reed is a reference to the results. The results appear to me to justify one in saying that the method is fairly accurate. If you refer to Table No. 2 you will see how close the correspondence is between the speeds of the mile posts corrected for tides, and the speeds by the log corrected for log rate. The difference is practically nothing. While looking at the table I should just like to refer to the remarks which Mr. White made. He said that the indicated horse-power corrected was not inserted in the table. For some reason or other this was omitted in the copy sent—there was not time to insert it in the first proof, but it will be included in the paper; but if Mr. White wishes to see it, the correction can be easily made by turning to the column for revolutions, where the mean revolutions of the run are given, and where the mean of the revolutions as corrected by Mr. Froude's method are stated. Mr. Samuda referred to improvements in the method of taking ordinary trials. By this method the time that the ship takes to pass over the mile is actually signaled and recorded on the cylinder, so that you get it with greater accuracy than you can with a watch, and the record is permanent. I am very pleased indeed that Mr. Samuda hit on all the difficulties that suggested themselves one by one to me in going through the analysis. Most of them he has noticed, and if he will do me the honor to read the paper again, he will see that I have endeavored to meet those difficulties, and to explain most of them away. Mr. Scott asked a question as to whether it had been tried on any other mile. I am sorry to say it has not, but I hope that the result of this discussion will be that it will be, and that the results of such will be brought forward at some future time. Now with reference to the round spots on the diagrams. Mr. Denny asked for an explanation as to how those spots at the beginning and end of the mile were got. The two observers notice when the ship passes the mile post, exactly in the same way as in the ordinary method, where you look at the watch when the two mile posts come in line; but instead of looking at the watch they signal with an electric contact-maker, so that you get, by the two of them signaling, the time the ship takes to pass over the distance between the sights. In that way you get a measure of the speed of the ship, *not through the water*, *but over the ground.* Then Mr. Denny referred to the *Stirling Castle.* Undoubtedly the *Stirling Castle* was a remarkably good result. I think it a great pity that some one had not had the opportunity of investigating this question of the *Stirling Castle*, because there is some reason for the result being so good, and it would be of great service to the profession if the causes of that could have been found out. There is also the question of the difficulty of determining the horse-power, and that leads one to the question that must come up for solution at some time; that is, the necessity for an integrating indicator, one that will record continuously the amount of power that is being developed. That is a thing that should be taken in hand and worked out by some one as soon as possible, in order that these trials can be placed upon a really satisfactory basis. The horse-powers were taken at several times throughout the run. You will see in Table No. 2 for the slow-speed runs, that the horse-power is given at the beginning and at the end of the run. Mr. Jenkins suggested a method of changing the observers. That was a method which occurred to me with reference to eliminating the personal equation, but I prefer the method that was really adopted, that is, letting the observers stand at the sides and observe the same event, because I think it is likely that by changing the ends of the observers you change the personal equation.

Mr. SAMUDA. You may double the error instead of halving it.

Mr. BILES. Probably. With reference to the acceleration there is a difficulty in getting the ship down to a uniform speed. By this method you can see when a ship is accelerating her speed, and see when the speed is uniform, so that you can choose the uniform speed and base your data upon that. Mr. Hall referred to the trials at sea. The trials that were made in the *Thames* that Mr. Hall spoke of were made in fairly rough weather, that is, ordinary weather that one might expect to meet at sea, and the results have been worked out and compare very well, so that I think that we have good reason to expect that the thing may be of value in the way in which Mr. Hall wishes it to be of value; that is, with regard to ships connected with his company, which on their passage from Plymouth to London may have these experiments performed on them for the purpose of determining the horse-power and speed. Mr. Purvis made a remark which I hope will not have too much weight. That is with reference to the discipline necessary, and the amount of work necessary to do this, because it would be really a serious drawback to the carrying out of these trials if what he says were absolutely necessary. There are four boys of about sixteen years of age necessary to observe these results. I think that is not a large staff, and I hope you will not place too much importance upon that. Now with reference to the time curve. This result that Mr. Purvis has shown here does not correspond. I have had some talk about it with him. The first thing that suggests itself to one is the question whether the tide curve is uniform day by day; whether it does not vary with the phase of the moon and the set of the tide—I mean the actual quantitative result. I think that is possible, but it is difficult to say whether it is actually so or not. I should like to remark, in the first place, that Mr. Froude has carried out a similar investigation, and has determined tide curves of a similar character to these at Skelmorlie. I think Mr. Jenkins will bear me out in that.

Mr. P. JENKINS. Those curves are much steeper and much higher, to begin with, than the curves shown in the diagrams here, the tide at Stokes Bay being sometimes as high as three knots.

Mr. BILES. Quite so; but it is the character of the curves I am referring to. I have had some correspondence with Mr. Froude upon the subject, and I find that the results generally agree. The next thing is what Mr. Purvis spoke of with regard to his trial of a vessel of theirs, which gave a very extraordinary result; against the tide the speed was 14 knots, and with the tide the speed was 13½, I think. I am not quite sure that I can explain it; although I have it clear in my own mind, it is somewhat difficult to explain it before an audience. Mr. Denny has told me that the second run, or rather the run that gave the highest speed finally, was taken about half an hour after high water, when they supposed there was slack water. Now supposing you take a run here which you assume to be with the tide; you get about a tenth of a knot to help you, and you go along only for half an hour, and then you turn round. Say that this is the point of high water. You then turn round for half an hour after high water and say it is slack water. But this result shows here that instead of being slack water the tide is actually at its maximum if this is true, and you have a tide of three-quarters of a knot an hour to help or hinder you. That might to a certain extent explain the difficulty. I think that is borne out to some extent by this. I have noticed particularly in the Clyde that before high water the rise of tide is very slow for an hour, but directly you turn high water the tide goes out very rapidly, and that to some extent bears out this curve. Mr. White has pointed out what I was going to remark was one great advantage of this, viz, the permanence of the record. You can take it into a court of law or analyze the thing afterwards. Anybody who has counted the revolutions of an engine will know that it always is a question of dispute whether so many revolutions were got over or not.

Sir EDWARD REED. They always want one or two more.

Mr. BILES. Then the question of engine friction was referred to by Mr. Purvis. I am sorry that I could not deal with that question, but the paper had already exceeded the length permissible in papers of this kind; but there is plenty of work for a lot of people in taking up this question of engine friction. Mr. Froude entertained a certain opinion with regard to engine friction, but it has been looked upon by other people as being a settled question that engine friction could be easily settled by progressive speed trials. The result of my observations on the question, and Mr. Purvis's and Mr. Denny's firms generally, is that it is a very difficult thing to determine what the engine friction really is; whether it is a constant friction or not has never been determined. I think the thing might be settled. Mr. White probably knows something that he might tell us on the question at some time with respect to Mr. Froude's turbine, which will probably give us more light on the question, but at present the question of engine friction is in a very unsettled condition. Mr. Jordan suggested having a gun. I may say that the thing is in process of construction—something in the shape of a catapult, with a guide pipe to throw it. But I must thank him for the idea of having it connected with the instrument, to record when the thing is thrown. That had not occurred to me. Mr. Withy asked whether any advantage was to be got from this. I cannot say with certainty whether there is any advantage, but I think it will be worth Mr. Withy's while to try this and find out whether there is. I must thank you, my lord and gentlemen, for the very favorable reception you have given my paper.

The PRESIDENT. Gentlemen, I have only one single word to say. We have had previous proofs of Mr. Biles's ability and power of research, and I think I may venture to claim for him that he has added to the high reputation he has already acquired within these walls. We have heard a good deal in the course of the last two days about the antics of steel, but they appear to me to be nothing as compared to the eccentricities of humps, and if I may venture to suggest to some of our young talent a scope and a field for investigation, I should recommend them to apply their abilities to ascertaining the causes of humps. I am quite sure you will allow me to convey to Mr. Biles our thanks for his able paper, and I am equally sure he has no possible reason to complain of want of criticism, because his paper has certainly been submitted to the keenest and closest criticism of any paper read during the present session.

SPEED AND CARRYING OF SCREW STEAMERS.

TABLE I.—*Steamers at load draught.*

CLYDE STEAMERS.

Letter.	Molded dimensions.	Steel or iron.	Class at Lloyd's.	Description.	Load draught molded.	Load displacement.	Percentage ratios. Molded draught to breadth.	Displacement to prism.	A to D	H to D	C to D	d to D	$\frac{L}{B}$	Kirk's analysis. A	B	C	Angle.	Surface.	Average speed at sea.
						Tons.											° ′		*Knots.*
O	390′ × 42′ × 34′.......	Steel.	100 A spar-decked.	Long midship house.	23. 58	7, 618	56. 1	71. 7	27. 9	10. 7	12. 3	50. 9	9. 30	110. 8	20. 23	168. 4	10 21	29, 880	14
P	390′ × 42′ × 31′.......	Steel.	100 A spar-decked.	Monkey f'castle and midship houses.	22. 33	7, 460	53. 2	74. 4	24. 0	10. 4	7. 68	42. 2	9. 29	100. 2	20. 15	189. 6	11 22	29, 280	$11\frac{1}{2}$
Q	380′ × 40′ × 30′ 6″....	Iron.	100 A 3-decked.	Monkey f'castle and midship houses.	22. 58	6, 780	56. 5	72. 9	26. 9	8. 47	8. 45	43. 8	9. 50	103. 2	18. 97	73. 6	10 29	27, 810	$11\frac{1}{3}$
R	320′ × 40′ × 28′ 6″....	Steel.	100 A 3-decked.	Full poop, midship houses, and f'castle.	22. 67	6, 380	56. 7	79. 7	20. 2	8. 12	4. 72	33. 2	8. 00	64. 8	19. 29	190. 4	16 35	24, 610	10
S	285′ × 35′ × 25′.......	Steel.	100 A 3-decked.	Midship house and f'castle.	18. 87	3, 297	54. 0	65. 7	25. 0	13. 3	15. 0	53. 4	8. 14	97. 7	16. 31	89. 6	9 29	16, 980	14
T	350′ × 40′ × 32′ 6″....	Iron.	100 A spar-decked.	F'castle and small midship house.	21. 0	5, 516	52. 5	70. 4	27. 8	11. 9	9. 1	48. 8	8. 75	103. 8	18. 67	142. 4	10 11	24, 030	13
U	430′ × 44′ × 36′.......	Iron.	....	....	22. 92	8, 200	52. 1	72. 4	34. 3	17. 2	13. 4	64. 9	9. 77	118. 7	20. 11	192. 6	9 37	32, 390	15
V	515′ × 52′ × 40′ 9″....	Steel.	....	....	25. 17	12, 450	48. 4	71. 1	34. 1	13. 3	13. 7	61. 0	9. 90	148. 8	23. 64	217. 4	9 2	43, 430	17
W	313′ 6″ × 34′ $1\frac{1}{2}$″ × 25′ 5″	Iron.	....	....	16. 29	2, 860	47. 7	65. 3	36. 7	13. 3	12. 2	62. 2	9. 22	109. 0	15. 01	95. 5	7 50	16, 420	$14\frac{1}{3}$
	Means 375′......	......	....	....	....	....	53. 0	71. 5	28. 5	11. 9	10. 7	51. 1	9. 1	....	....	....	....	....	......

GOVERNMENT DISPATCH VESSEL.

X	300′ × 45′ 10″ × 27′ 1½″	Steel.	....	....	18.75	3,735	40.9	56.5	28.2	10.3	27.1	65.6	6.54	130.5	20.56	39.0	8 57	18,340	16

FAST TORPEDO BOAT.

Y	101′ 5″ × 12′ 6″ / 11′ 2″ } × 5′ 0″	Steel.	....	....	3.0	40.1	26.9	56.5	35.5	1.9	42.4	79.8	9.08	44.07	4.08	13.23	5 17	1,078	22½

MEANING OF REFERENCE LETTERS IN ABOVE COLUMNS.—A = Weight of net iron or steel in hull. H = Woodwork, outfit, &c., in hull. C = Machinery weight. d = Light isplacement. D = Load displacement. L = Length. B = Breadth molded.

TABLE 2.—*Tyne, Wear, and Hartlepool steamers—all iron. At load draught.*

WITH CONTINUOUS UPPER DECK.

Letter.	Molded dimensions.	Class at Lloyd's.	Description.	Load draught molded.	Load displacement.	Percentage ratios. Molded draught to breadth.	Percentage ratios. Displacement to prism.	Percentage ratios. A to D	Percentage ratios. H to D	Percentage ratios. C to D	Percentage ratios. d to D	L/B	Kirk's analysis. A	Kirk's analysis. B	Kirk's analysis. C	Kirk's analysis. Angle.	Kirk's analysis. Surface.	Average speed at sea.
				′ ″	*Tons.*											° ′		*Knots.*
A	300′ × 38′ × 29′ 6″	100 A awning-deck.	....	21 7	5,060	56.8	77.5	21.0	4.98	7.21	33.2	7.89	67.6	17.66	164.8	14.38	21,360	10
B	300′ × 38′ 6″ × 29′ 6″	100 A spar-deck.	....	23 8	5,670	61.5	76.0	19.8	3.76	6.44	30.0	7.79	71.9	18.39	156.2	14.21	22,800	10
C	243′ × 33′ 10″ × 24′ 6″	100 A spar-deck.	....	19 3	3,225	56.9	77.4	21.1	6.76	4.96	32.9	7.18	54.9	15.58	133.2	15.50	15,390	10
D	278′ 6″ × 35′ 3″ × 24′ 5″	100 A 3-deck..	Cape aft, midship houses, and T. G. F'castle.	20 $2\frac{1}{2}$	4,050	57.3	76.0	23.5	4.17	5.18	32.8	7.90	67.0	16.56	144.5	13.53	18,430	9
E	260′ × 33 10″ × 24′ $0\frac{1}{2}$″	....	Midship houses and T. G. F'castle.	19 2	3,745	56.7	78.8	21.5	8.09	4.00	33.5	7.68	55.2	16.68	149.6	16.49	16,990	$8\frac{1}{2}$
F	285′ × 35′ $9\frac{1}{2}$′ × 25′ 2″	....	Midship houses and T. G. F'castle.	20 $1\frac{1}{2}$	4,569	56.2	84.0	20.9	8.30	4.40	33.6	7.96	45.6	16.60	193.8	20.0	19,650	$8\frac{3}{4}$
G	280′ × 34′ × 25′ 6″	100 A 3-deck..	Midship houses and sunk F'castle.	20 2	3,950	59.3	79.1	21.5	4.40	4.81	30.7	8.23	58.5	15.47	163.0	14.48	18,300	$9\frac{1}{2}$ to 10
H	285′ × 35′ × 25′ 6″	100 A 3-deck..	Full poop, midship houses, and T. G. F'castle.	20 2	3,905	57.6	70.0	23.0	5.76	5.12	33.9	8.14	85.5	16.97	114.0	11.13	18,390	9 to 10
I	285′ × 36′ × 25′ 6″	100 A 3-deck..	Full poop, midship houses, and T. G. F'castle.	20 8	4,480	57.4	76.9	22.9	5.69	4.91	33.5	7.92	65.7	17.29	153.6	14.45	19,540	9 to $9\frac{1}{2}$

J	290′ × 37′ × 28′ 6″	100 **A** 3-deck..	Midship houses.........	21 8	4,710	58.6	76.3	21.9	6.47	5.63	34.0	7.84	68.8	17.19	152.4	14.2	20,350	10 to 11
	Means 280′ 6″.	....	....	....	....	57.8	77.2	21.7	5.84	5.27	32.8	7.85	......	....	....	....	....	....
						WITH QUARTER-DECK.												
K	263′ 6″ × 35′ 8″ × 20′ 6″	100 A 2-deck..	Long quarter-deck......	19 3	3,740	54.0	77.6	22.0	4.44	4.81	31.3	7.39	59.0	16.62	145.5	15 44	17,120	9
L	249′ × 33′ 10″ × 18′ 6″	100 A 2-deck..	Long quarter-deck......	17 3	3,030	51.0	76.1	22.2	5.84	5.28	33.3	7.36	59.6	16.23	129.8	15 14	14,890	9¼
M	243′ 9″ × 31′ 10″ × 19′ 2½″	....	Long quarter-deck......	17 3½	2,838	54.3	77.6	23.6	10.10	4.20	37.9	7.66	54.5	15.16	134.7	15 33	14,320	9
N	257′ 6″ × 34′ 4″ 20′ 4½″	....	Long quarter-deck.	18 4	3,617	53.4	81.9	21.9	6.99	4.84	33.7	7.50	46.5	16.37	164.5	19 24	16,560	9¼
	Means 253′ 5″ .	....	....	....	....	53.2	78.3	22.4	6.84	4.78	34.0	7.48	......	....	....	....	....	....

MEANING OF REFERENCE LETTERS IN ABOVE COLUMNS.—A = Weight of net iron in hull. H = Weight of wood, outfit, &c. C = Weight of machinery. d = Light displacement. D = Load displacement. L = Length. B = Breadth molded.

TABLE 3.—*Clyde steamers.*

[Draught = .55 of breadth.]

Letter.	Molded dimensions.	Steel or iron.	Molded draught = .55 of breadth.	Displacement.	Percentage ratios.					$\frac{L}{B}$	Kirk's analysis.				
					Displacement to prism.	A to D	H to D	C to D	d to D		A	B	C	Angle.	Surface.
				Tons.										° ′	
O	390′ × 42′ × 34′	Steel	23.1	7,450	71.5	28.5	11.0	12.6	52.1	9.29	111.2	20.23	167.6	10 19	29,460
P	390′ × 42′ × 31′	Steel	23.1	7,750	74.6	23.1	10.0	7.4	40.6	9.29	99.0	20.17	192.0	11 31	29,940
Q	380′ × 40′ × 30′ 6″	Iron	22.0	6,580	72.6	27.7	8.7	8.7	45.1	9.50	104.2	18.97	171.6	10 19	27,330
R	320′ × 40′ × 28′ 6″	Steel	22.0	6,170	79.4	20.9	8.4	4.9	34.2	8.00	66.0	19.32	188.0	16 19	24,140
S	285′ × 35′ × 25′	Steel	19.25	3,380	67.5	24.4	13.0	14.6	52.2	8.14	92.7	15.97	99.6	9 46	17,220
T	350′ × 40′ × 32′ 6″	Iron	22.0	5,840	70.8	26.3	11.2	8.6	46.1	8.75	102.3	18.75	145.4	10 23	24,840
U	430′ × 44′ × 36′	Iron	24.2	8,780	73.1	32.0	16.1	12.5	60.6	9.77	115.8	20.21	198.4	9 54	33,650
V	515′ × 52′ × 40′ 9″	Steel	28.6	14,690	73.0	28.9	11.2	11.6	51.7	9.90	139.2	23.91	236.6	9 45	47,670
W	313′ 6″ × 34′ 1½″ × 25′ 5″	Iron	18.8	3,450	67.0	30.4	11.0	10.1	51.6	9.22	103.5	15.29	106.5	8 24	18,300
	Means, 375′				72.2	26.9	11.2	10.1	48.2	9.10					
	Means, 382′ (without R)				71.3	27.7	11.5	10.8	50.0	9.23					

MEANING OF REFERENCE LETTERS IN ABOVE COLUMNS.—A = Net iron or steel in hull. H = Woodwork, outfit, &c. C = Weight of machinery. *d* = Light displacement. D = Displacement. L = Length. B = Breadth molded.

TABLE 4.—*Tyne, Wear, and Hartlepool steamers, all iron, with continuous upper deck.*

[Draught = .55 of breadth.]

Letter.	Molded dimensions.	Molded draught = .55 of breadth.	Displacement.	Percentage ratios.					$\frac{L}{B}$	Kirk's analysis.				
				Displacement to prism.	A to D	H to D	C to D	*d* to D		A	B	C	Angle.	Surface.
			Tons.										° ′	
A	300′ × 38′ × 29′ 6″	20.9	4,860	77.0	21.9	5.18	7.51	34.6	7.89	68.9	17.61	162.2	14 20	20,860
B	300′ × 38′ 6″ × 29′ 6″	21.17	4,970	74.9	22.6	4.29	7.34	34.2	7.79	75.2	18.28	149.6	13 40	21,110
C	243′ × 33′ 10″ × 24′ 6″	18.61	3,100	77.2	22.0	7.03	5.16	34.2	7.18	55.3	15.53	132.4	15 41	15,030
D	278′ 6″ × 35′ 3″ × 24′ 5″	19.39	3,850	75.5	24.7	4.39	5.45	34.5	7.90	68.3	16.53	141.9	13 36	17,910
E	260′ × 33′ 10″ × 24′ 0½″	18.61	3,630	78.7	22.2	8.37	4.13	34.7	7.68	55.4	16.68	149.2	16 45	16,680
F	285′ × 35′ 9½″ × 25′ 2″	19.69	4,450	83.7	21.5	8.50	4.50	34.5	7.96	46.5	16.57	191.0	19 37	19,360
G	280′ × 34′ × 25′ 6″	18.7	3,595	78.3	23.6	4.84	5.28	33.8	8.23	60.8	15.35	158.4	14 10	17,340
H	285′ × 35′ × 25′ 6″	19.25	3,705	69.7	24.3	6.07	5.40	35.8	8.14	86.4	16.96	112.2	11 06	17,840
I	285′ × 36′ × 25′ 6″	19.8	4,260	76.5	24.1	5.99	5.16	35.2	7.92	67.0	17.27	151.0	14 27	18,990
J	290′ × 37′ × 28′ 6″	20.35	4,360	75.6	23.6	6.99	6.08	36.7	7.84	70.7	17.10	148.6	13 36	19,470
	Means, 280′ 6″			76.7	23.0	6.17	5.60	34.8	7.85					
	Means, assuming a finer ratio of displacement to prism			72.0	24.5	6.57	5.97	37.1	7.85					

MEANING OF REFERENCE LETTERS IN ABOVE COLUMNS.—A = weight of net iron in hull. H = weight of woodwork, outfit, &c., in hull. C = weight of machinery. *d* = Light displacement. D = Displacement. L = Length. B = breadth, molded.

Table 5.—*Steamers at trial draughts.*

Letter.	Molded dimensions.	Steel or iron.	Molded trial draught.	Trial displacement.	Percentage ratios. Displacement to prism.	Percentage ratios. Molded draught to breadth.	Percentage ratios. A to D	Percentage ratios. H to D	Percentage ratios. C to D	Percentage ratios. *d* to D	$\frac{L}{B}$	Kirk's analysis. A	Kirk's analysis. B	Kirk's analysis. C	Kirk's analysis. Angle.	Kirk's analysis. Surface.	Maximum speed.	Maximum I. H. P.	Maximum I. H. P. ÷ trial displacement in tons.
	CLYDE STEAMERS.																		
				Tons.											° ′		*Knots.*		
O	390′ × 42′ × 34′	Steel..	17.75	5,405	68.7	42.3	39.3	15.1	17.3	71.8	9.29	122.0	19.89	146.0	9 16	24,620	15.93	5,140	.960
R	320′ × 40′ × 28′ 6″	Steel..	16.25	4,370	77.5	40.6	29.6	11.9	6.9	48.3	8.00	72.1	18.98	175.8	14 45	19,970	11.65	1,665	.381
S	285′ × 35′ × 25′	Steel..	14.93	2,425	62.3	42.7	34.0	18.1	20.4	72.6	8.14	107.4	16.00	70.2	8 28	14,268	15.39	2,907	1.200
U	430′ × 44′ × 36′	Iron ..	18.42	6,125	68.9	41.9	45.9	23.0	18.0	86.9	9.77	133.9	19.65	162.2	8 21	27,920	15.67	5,110	.834
W	313′ 6″ × 34′ 1½″ × 25′ 5″	Iron ..	14.58	2,441	63.5	42.7	43.0	15.6	14.3	72.9	9.22	114.4	14.71	84.7	7 20	15,050	15.2	2,290	.938
	GOVERNMENT DISPATCH BOAT.																		
X	300′ × 45′ 10″ × 27′ 1″	Steel..	17.17	3,290	54.8	37.4	32.1	11.7	30.7	74.5	6.54	135.5	20.35	29.00	8 33	17,118	18.59	7,556	2.30
	FAST TORPEDO BOAT.																		
Y	101′ 5″ × {12′ 6″ / 11′ 2″} × 5′	Steel..	3.0	40.1	56.5	26.9	35.5	1.9	42.4	79.8	9.08	44.07	4.08	13.23	5 17	1,078	22.5	620	15.4

Meaning of reference letters in above columns.—A = Weight of iron or steel in hull. H = Weight of wood outfit, &c., in hull. C = Weight of machinery. *d* = Light displacement. D = Displacement. L = Length. B = Breadth molded.

TABLE 6.—*Indicated horse-power and weights of machinery.*

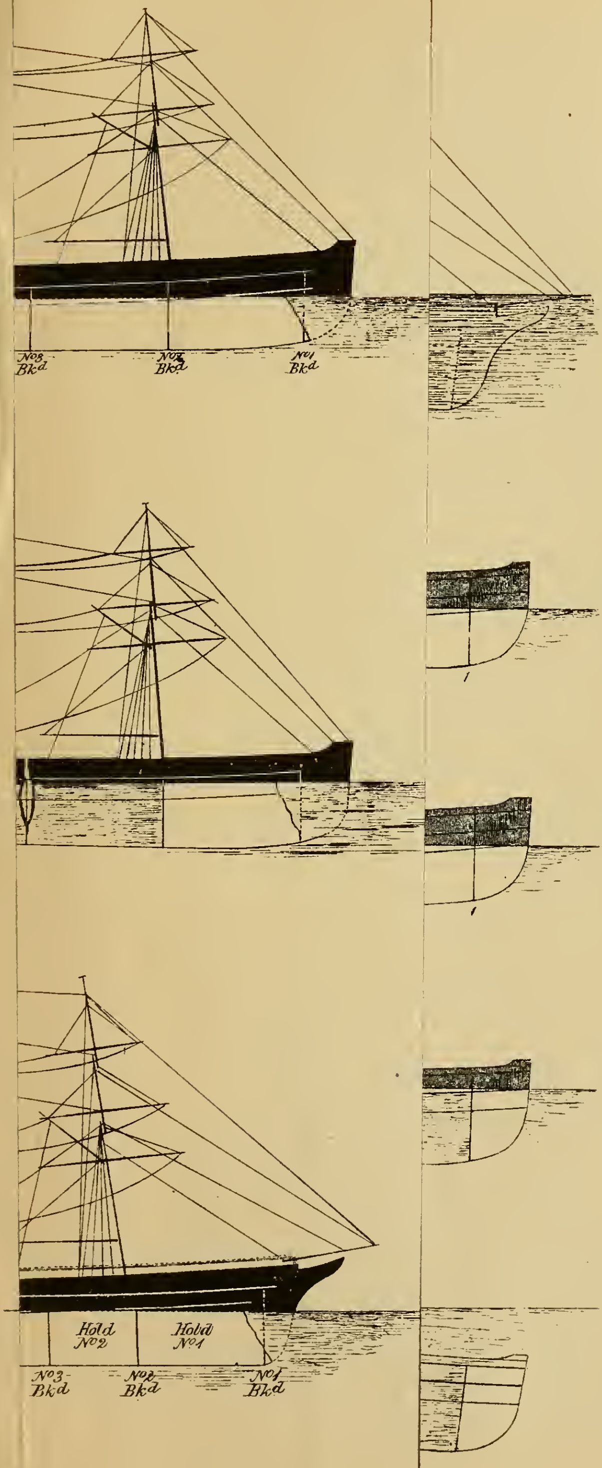
Steamer.	P. Maximum mean I. H. P.	W. Weight of machinery with steam up.	$\frac{P}{W}$
		Tons.	
O	5, 140	937	5. 48
P	2, 821	573	4. 92
R	1, 665	300	5. 55
S	2, 907	495	5. 87
U	5, 110	1, 100	4. 65
W	2, 290	350	6. 54
X	7, 556	1, 011	7. 47
Y	620	17	36. 5
Z	6, 624	998	6. 64

TABLE 7.—*Tonnage launched during* 1879, 1880, *and* 1881 *on the Clyde, Tyne, Wear, and Tees, with the ratios of the Clyde tonnage to the whole, and the average tonnage of vessels launched in each year.*

	1879.		1880.		1881.	
	Number.	Tons.	Number.	Tons.	Number.	Tons.
Number of ships and tonnage built on the—						
Clyde	191	174, 750	209	248, 655	261	341, 022
Tyne	130	139, 843	109	148, 723	114	176, 830
Wear	63	88, 643	76	114, 832	90	154, 932
Tees	25	31, 756	38	48, 506	33	58, 345
Totals	409	434, 992	432	560, 716	498	731, 129
Ratio of Clyde tonnage to total tonnage per cent.	40. 18		44. 3		46. 67	
Average tonnage of vessels launched:						
Clyde	914		1, 189		1, 306	
Tyne	1, 075		1, 364		1, 551	
Wear	1, 407		1, 511		1, 721	
Tees	1, 270		1, 276		1, 768	

○

Plate I.



No 3 Bkd
No 2 Bkd
No 1 Bkd
Hold No 2
Hold No 1
No 3 Bkd
No 2 Bkd
No 1 Bkd

Plate I.

Fig 1

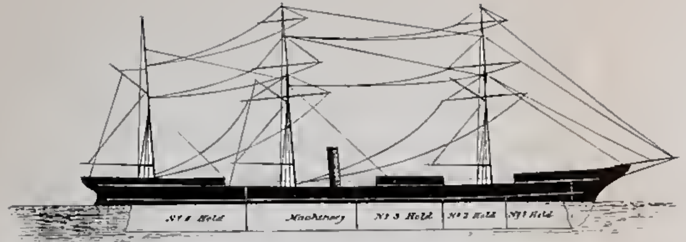


Fig 2

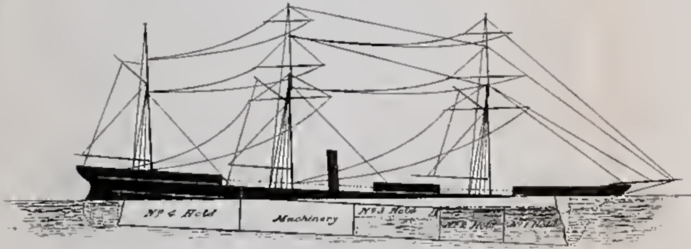


Fig 3.

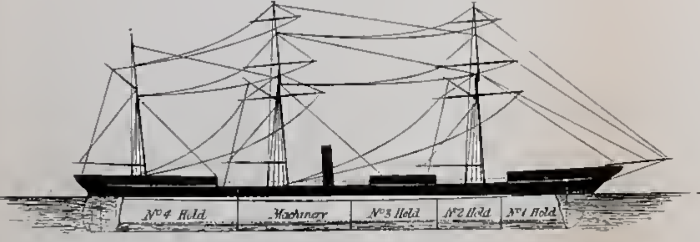


Fig 4

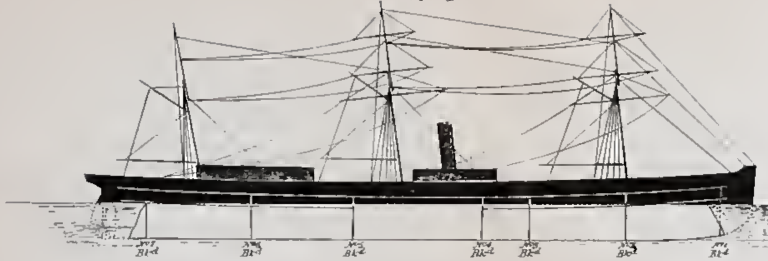


Fig 5

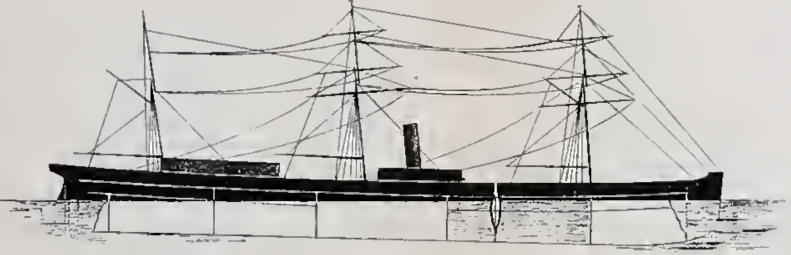


Fig 6

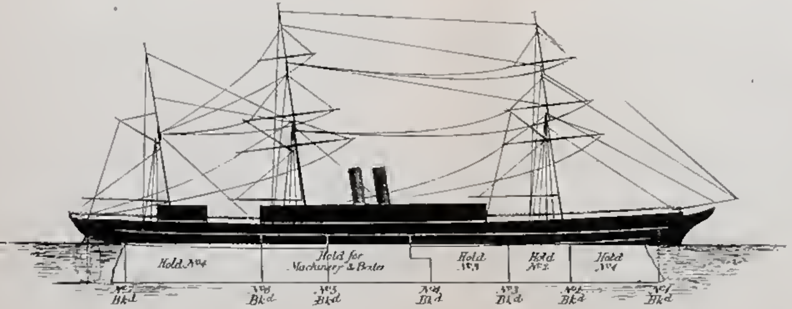
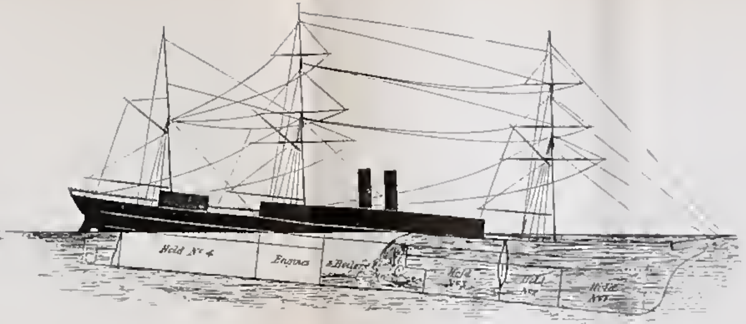
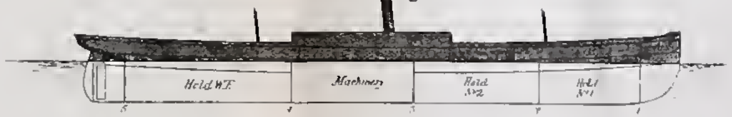


Fig 7

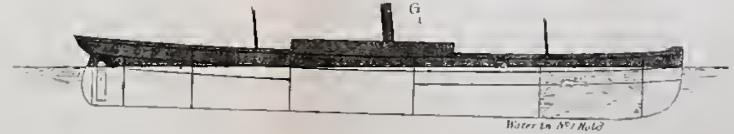


B



G

G_1



G_{11}

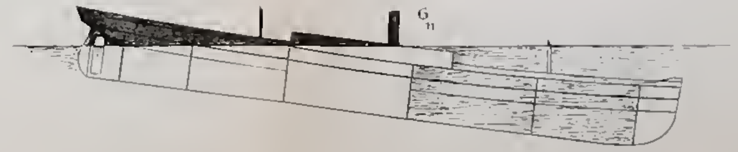


Plate II

A"

KING.

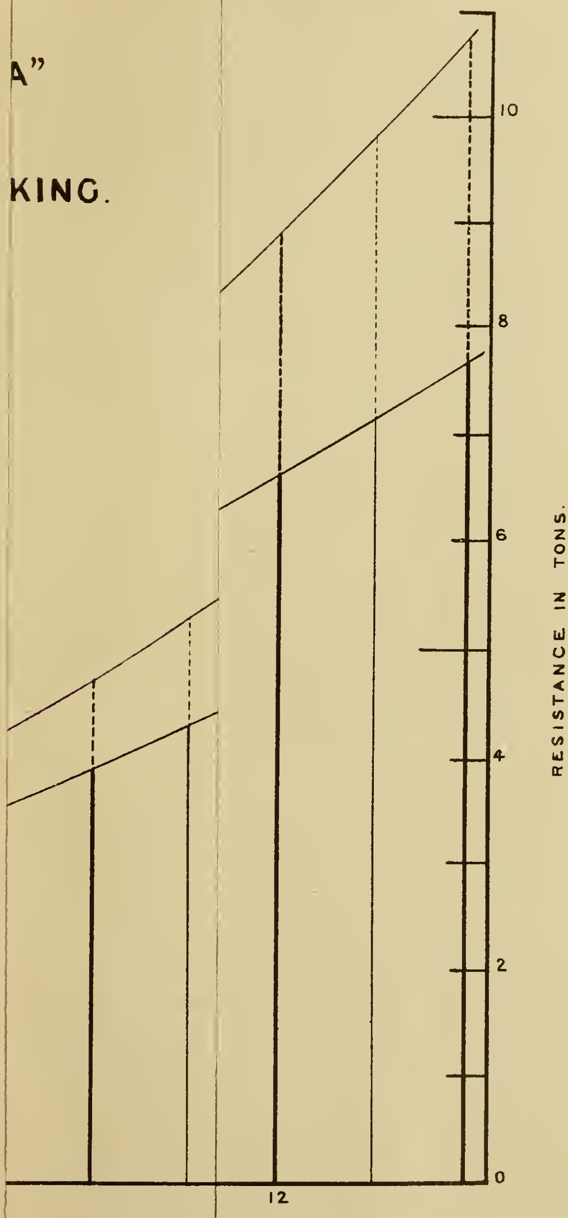


Plate II

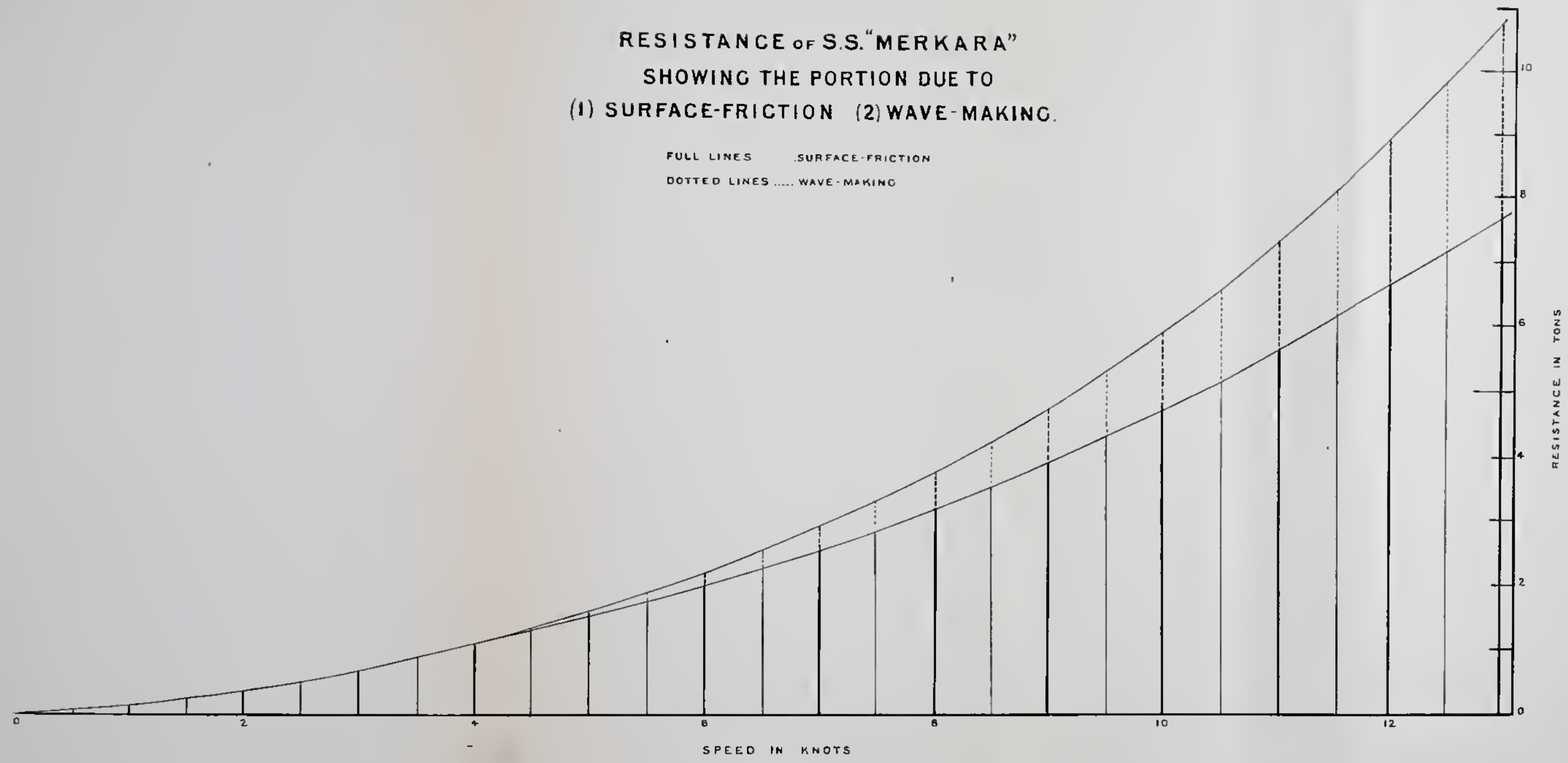

RESISTANCE OF S.S. "MERKARA"
SHOWING THE PORTION DUE TO
(1) SURFACE-FRICTION (2) WAVE-MAKING.
FULL LINES .... SURFACE-FRICTION
DOTTED LINES ..... WAVE-MAKING
SPEED IN KNOTS
RESISTANCE IN TONS
0
2
4
6
8
10
12

Plate III.

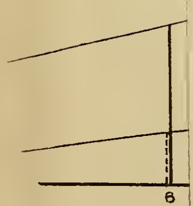
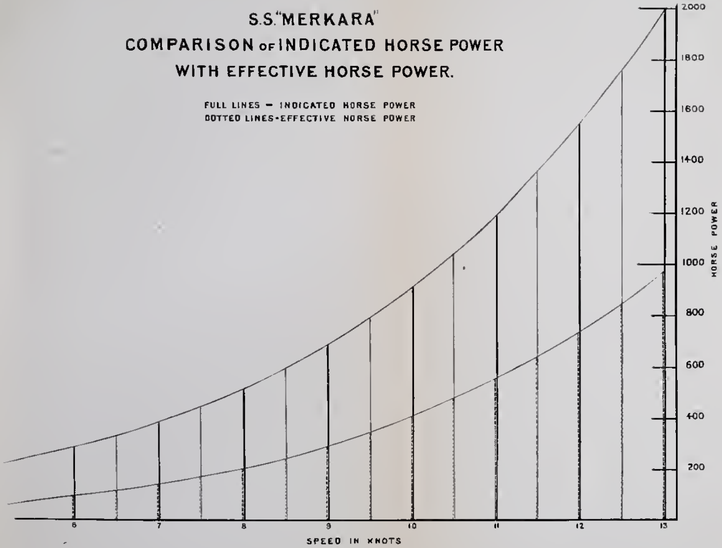


Plate III.



S.S. "MERKARA"
COMPARISON OF INDICATED HORSE POWER
WITH EFFECTIVE HORSE POWER.
FULL LINES — INDICATED HORSE POWER
DOTTED LINES - EFFECTIVE HORSE POWER
2000
1800
1600
1400
1200
1000
800
600
400
200
HORSE POWER
6
7
8
9
10
11
12
13
SPEED IN KNOTS

Plate IV.

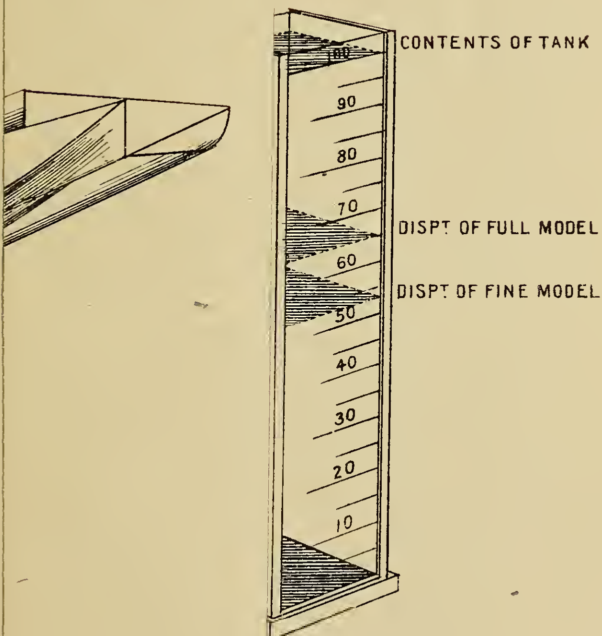
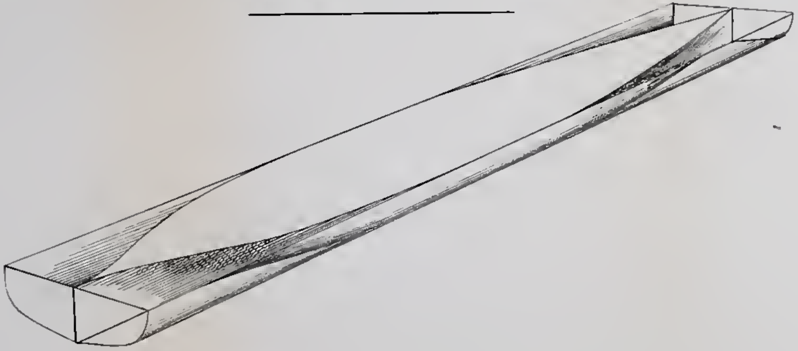

CONTENTS OF TANK
100
90
80
70
DISPT. OF FULL MODEL
60
DISPT. OF FINE MODEL
50
40
30
20
10

DIAGRAM ILLUSTRATIVE OF EXPERIMENT FOR PRISMATIC COEFFICIENT.

SECTION OF TANK & MODEL



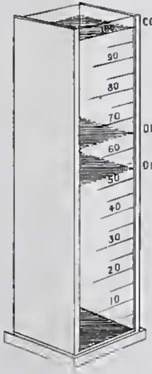
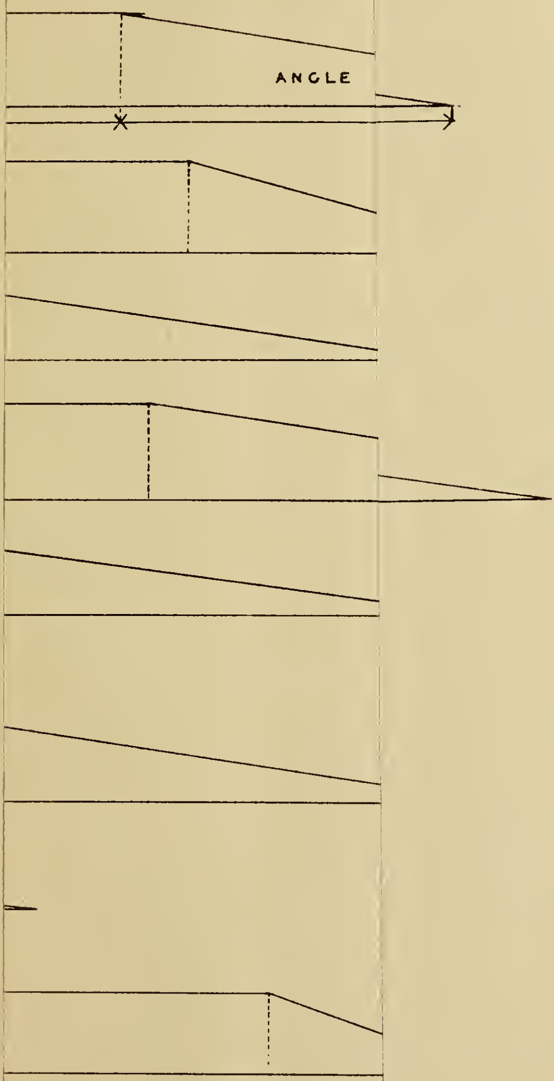
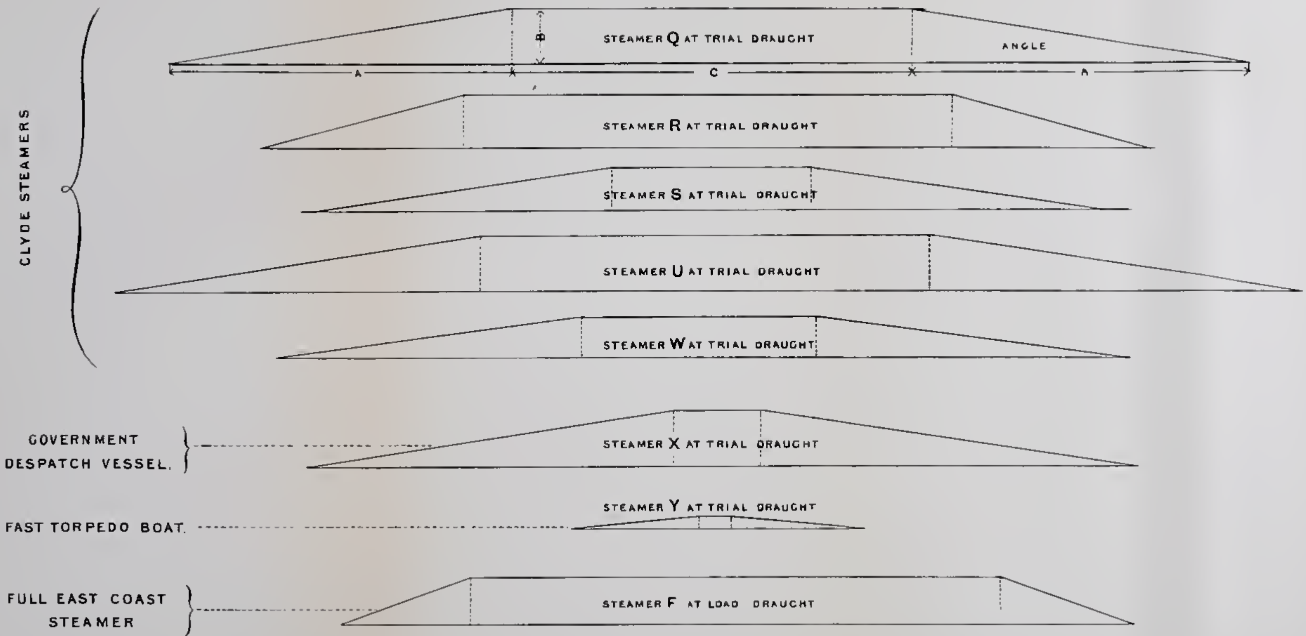


Plate V.

KIRK'S ANALYSIS



PLANS OF BLOCKS ILLUSTRATIVE OF KIRK'S ANALYSIS.



rials.

Plate VI.

7 Knots

ecs

to Knots per hour to get actual revs.

k Curves give speed of Ship in Knots per hour.

nd end of Mile.

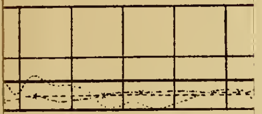
Log.

that the forward and after observers noted

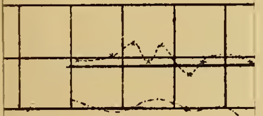
in this was made at the end of each Run.

Iean Speed, 11·93 Knots
Iean Revs, 51·91
Revs Cont, ·2266
Perl Equan, 267 Secs

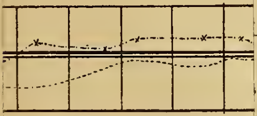
Iean Speed, 11·92 Knots
Iean Revs, 52·4
Revs Cont. ·2284
Perl Equan, 267 Secs



12·35 12·36



1·10 1·11 1·12



1·52 1·53

nots

(Continuation.)
Mean Speed, 11·03
Mean Revs, 47·15
Revs Const, ·2339
Perl Equan, 449

2·27 2·28 2·29

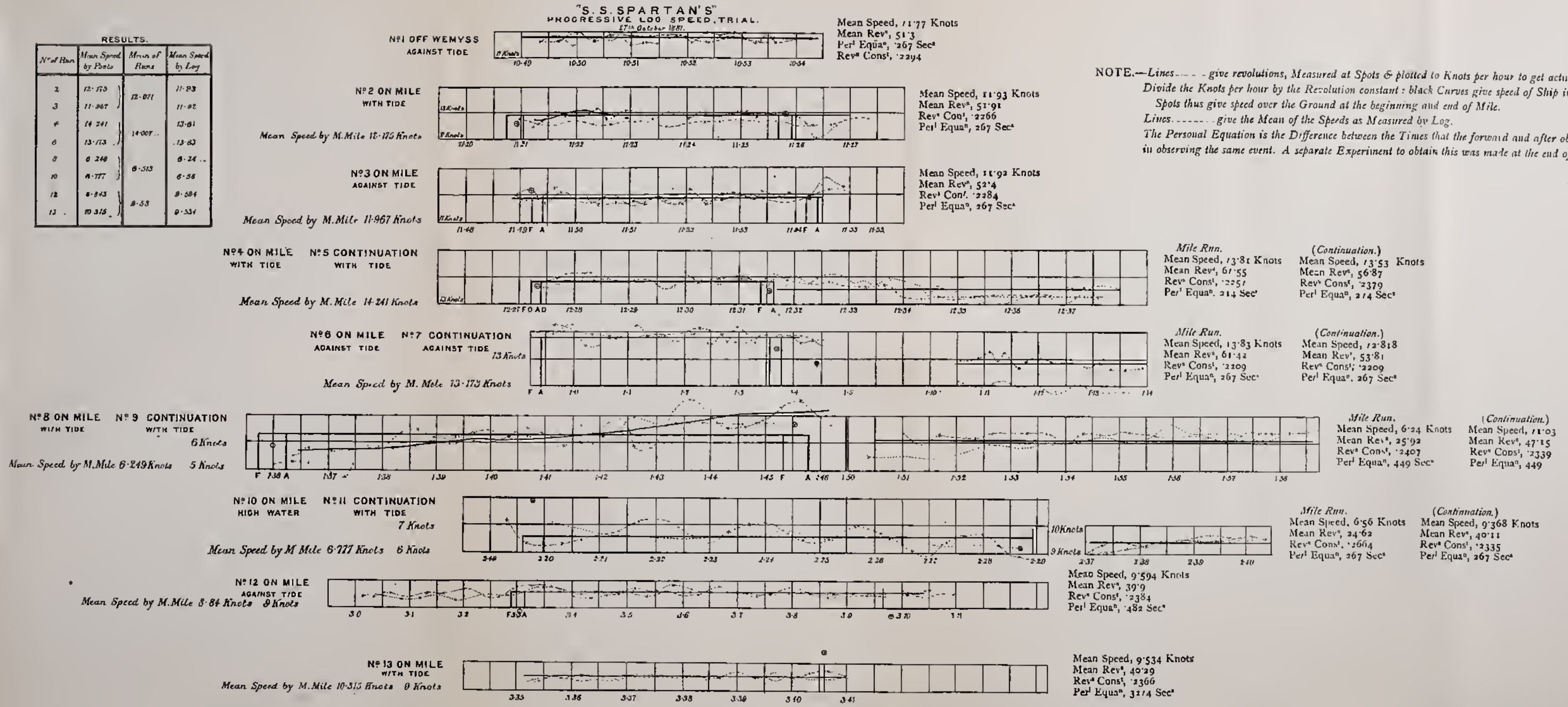
(Continuation.)
ean Speed, 9·368 Knots
ean Revs, 40·11
vs Cons', ·2335
l Equan, 267 Secs

3·11

Fig. 1.

RESULTS.

Nº of Run	Mean Speed by Posts	Mean of Runs	Mean Speed by Log
2	12·175	12·071	11·93
3	11·967		11·92
4	14·241	14·007	13·81
6	13·173		13·83
8	6·249	6·513	6·24
10	6·777		6·56
12	8·843	8·53	9·594
13	10·315		9·534



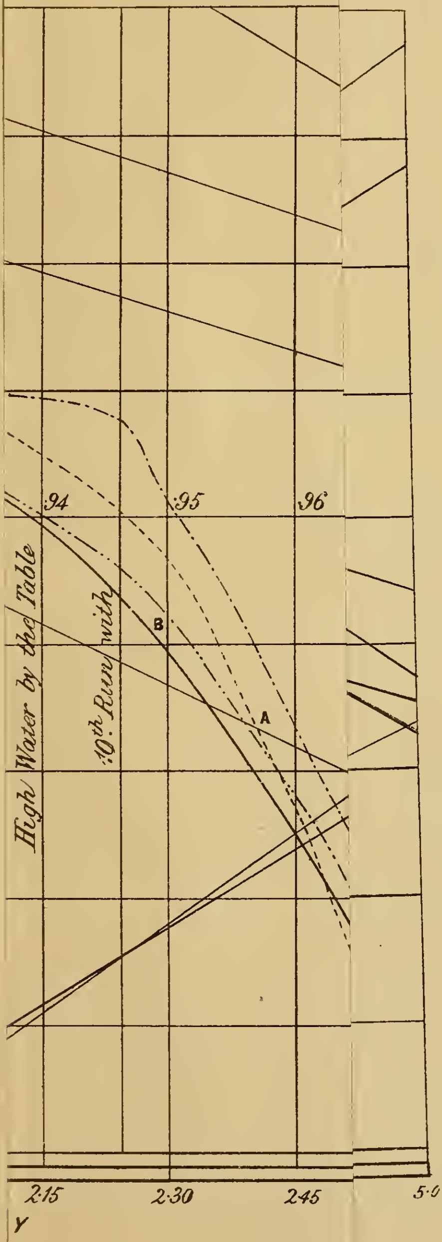
NOTE.—*Lines - - - - give revolutions, Measured at Spots & plotted to Knots per hour to get actual revs. Divide the Knots per hour by the Revolution constant: black Curves give speed of Ship in Knots per hour. Spots thus give speed over the Ground at the beginning and end of Mile. Lines. . . . . give the Mean of the Speeds as Measured by Log. The Personal Equation is the Difference between the Times that the forward and after observers noted in observing the same event. A separate Experiment to obtain this was made at the end of each Run.*

Plate VII.

iper on Progressive Spee

IING THE TIDE CURVE

2.



CURVE SHOWING THE METHOD OF DETERMINING THE TIDE CURVE AND LOG "RATE."

Fig. 2.

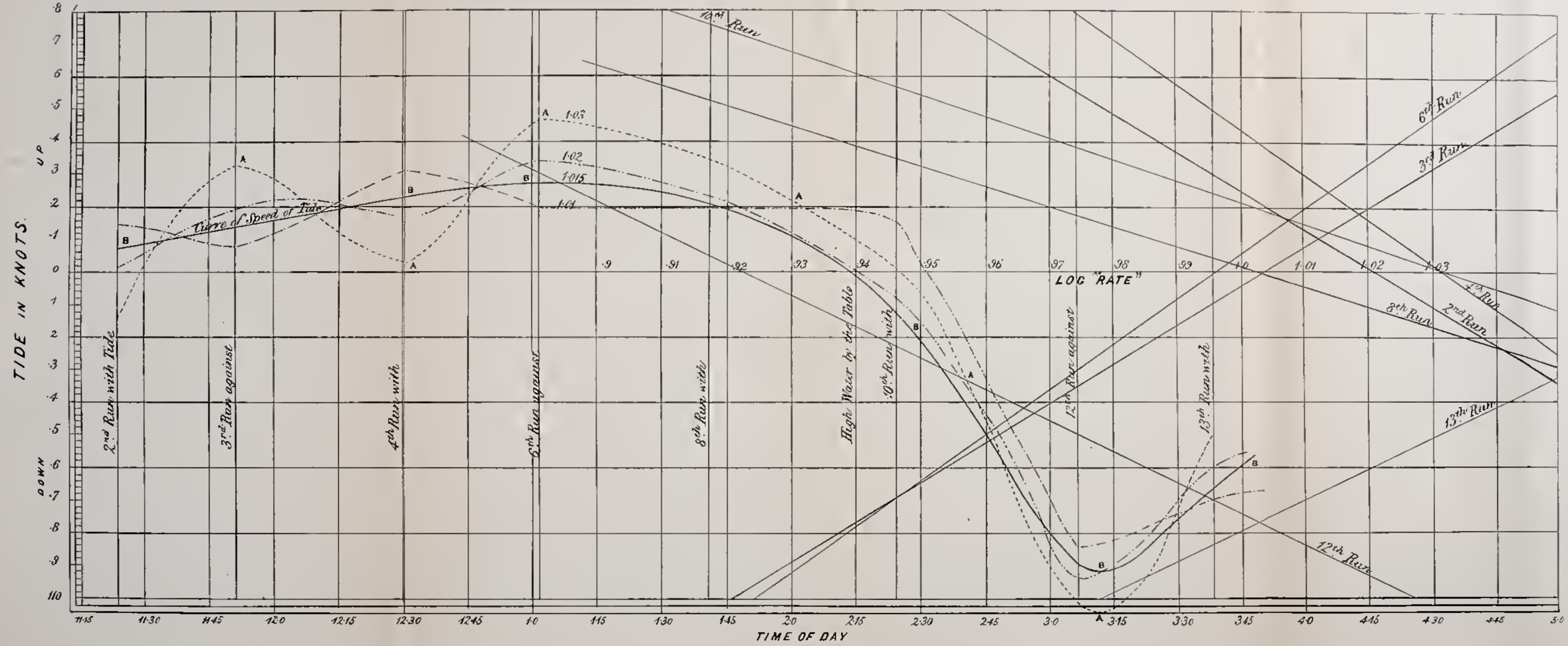


Plate VIII

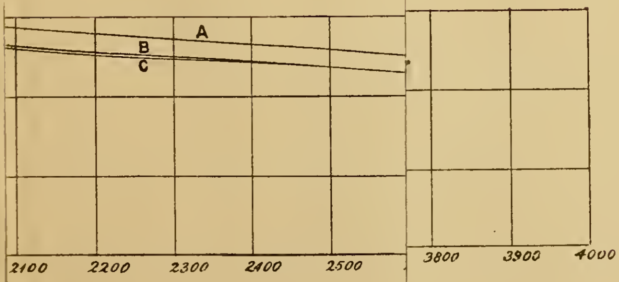
aper on Progressive Speed Trials.

F S.S. SPARTAN

d

for Log Rate & speed of Tide

for alteration by Mr. Froude's method.



To Illustrate Mr. J. Harvard Biles' Paper on Progressive Speed Trials.

CURVE OF I.H.P. OF S.S. SPARTAN

A - *Curve Plotted to Results as observed.*

B - *Curve Plotted to Results corrected for Log Rate & speed of Tide*

C - *Curve Plotted to Results corrected for alteration by Mr. Froude's method.*

Fig. 3.

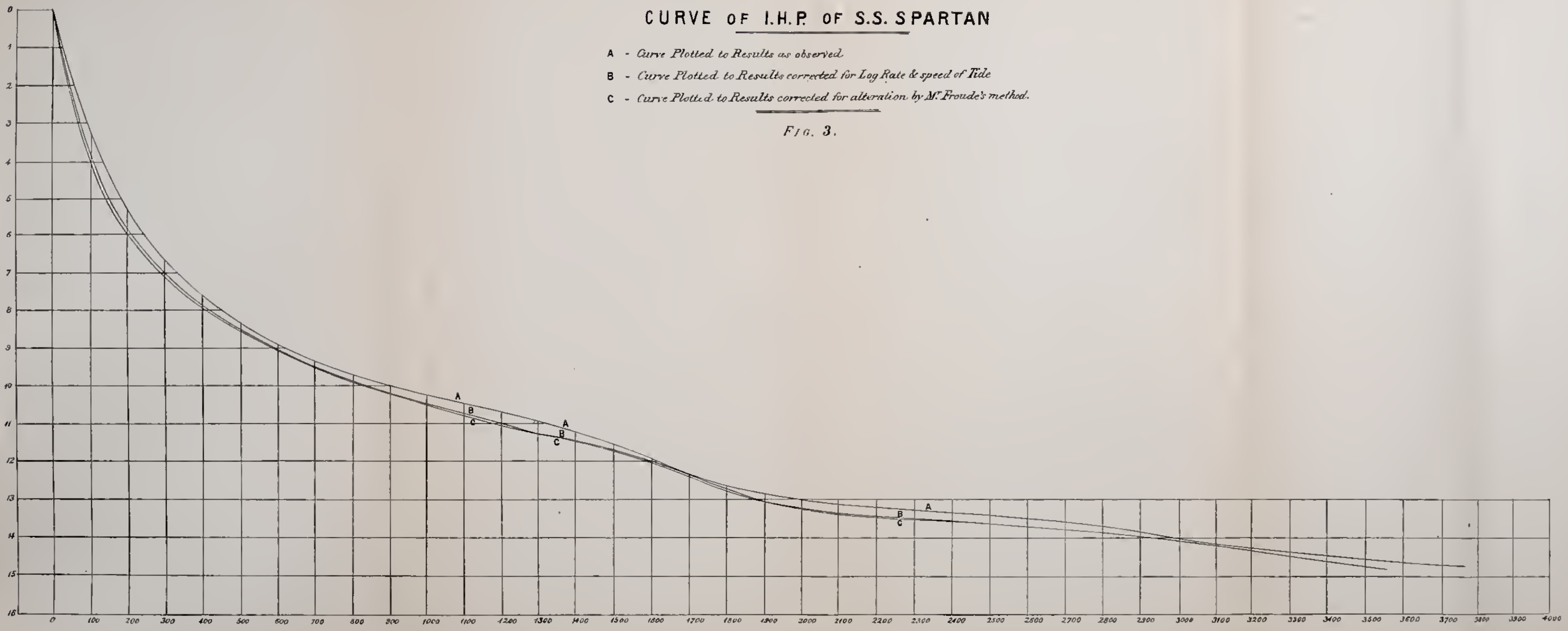


Plate IX.

ATOR.
,
IALS

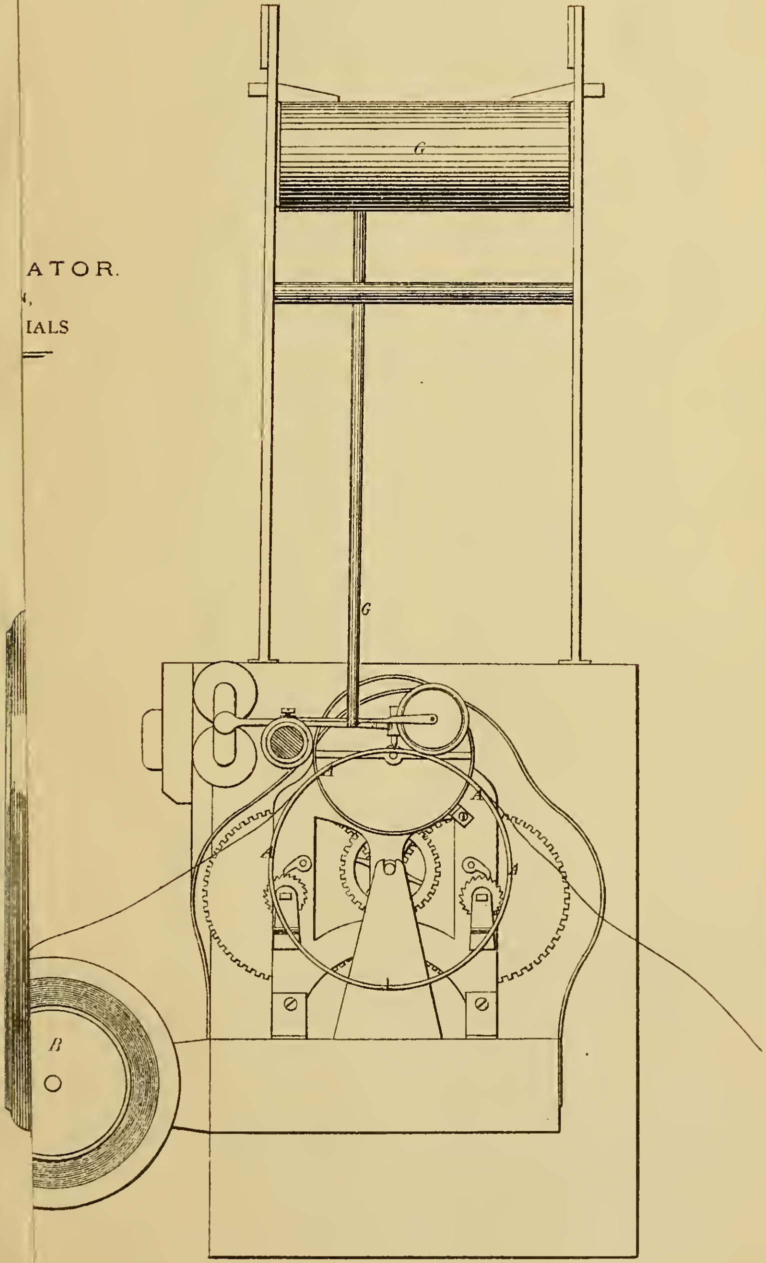


FIG. 4.

ELECTRIC SPEED INDICATOR

USED BY MESSRS J & G THOMSON,

FOR PROGRESSIVE SPEED MILE TRIALS